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PROTECTION COORDINATION OF THE KENNEDY SPACE CENTER ELECTRIC DISTRIBUTION NETWORK

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1. INTRODUCTION

This report describes the computerized procedures which have been developed for the protection coordination of the Kennedy Space Center Electric Distribution Network. The developed procedure enables the user to:

(1) Visualize the coordination and protection quality of any existing system of devices and settings by computer plotting the tripping characteristics of the involved devices on a common basis.

(2) Determine the optimum settings of a given set of protective devices and configuration in the sense of the best expected coordinated operation of these devices.

In the first case the computer procedure accepts data on the network configuration, protective devices and settings and provides a computerized plot of the overlayed current-time characteristics on a common scale. Thus the tedious hand plotting procedure is eliminated. For the KSC system, all basic protective elements have been computer modeled in the form of subroutines so that input device data is minimal - being only settings for adjustable elements.

The second procedure provides an optimization feature which results in a best coordination available from candidate systems. The user specifies the candidate devices and available settings of these devices. The computer program then compares all combinations of specified equipment with regard to coordination and selects the best set together with adjustment settings. If only one set of devices is specified, the program selects optimum adjustment settings for this set. The program

utilizes the Short Circuit Program as a subroutine to determine network fault currents to input to the device characteristic subroutines.

The developed procedure consists of a set of computer subroutines referred to as the coordination pack. The coordination pack is divided into five (5) sets of computer routines

(a) DEVICE CHARACTERISTIC SUBROUTINES

These are subroutines which simulate the time versus current characteristics of the different protective devices existing in the system. The following subroutines are included in this set.

RELIAC	- relays type IAC
RELACO	- relays type CO
BRKRAK	- breakers type AK
BRKRLA	- breakers type LA
BRKROD	- breakers type OD
BRKRDB	- breakers type DB
MCCBGE	- molded case breakers by G.E.
FUSEEJ	- fuses type EJO, EJ
FUSCLE	- fuses type CLE
FUSECL	- fuses type CL
FUSESM	- fuses type SM
FUNCTN	- this subroutine simulates a piecewise first degree function, and is used by the above subroutines

The above subroutines return the time to trip required by the corresponding device when the current is specified.

The user who becomes acquainted with these subroutines and with their format may obtain a computer representation of the particular device by calling the appropriate subroutine.

(b) COORDINATION INDEX COMPUTATION SUBROUTINES

This set of subroutines includes those which calculate probabilistic indices of coordination; namely, it includes the following subroutines:

FUSBRK	- calculates coordination indices between a fuse and a breaker
BRKBRK	- calculates coordination indices between two breakers
RELFUS	- calculates coordination indices between a relay and a fuse
RELBRK	- calculates coordination indices between a relay and a breaker

The above subroutines calculate the following probabilistic coordination indices A1, A2 and RSC, which are defined in the subsequent section. They use the set of subroutines (a) to characterize the protective elements and the Short Circuit Program to determine available fault currents.

(c) PROTECTION SUBROUTINES

Two subroutines have been developed to check protection:

CHECKH	- checks if the system is protected against overheating
CHECKS	- checks if the system is protected against motor starting currents.

These require data on heating characteristics of network elements and motor starting current vs time requirements. The above set of subroutines uses the set of subroutines (a).

(d) PLOTTING SUBROUTINE

This division includes a plotting program consisting of two parts:

a. the routine PLOT which creates the characteristics to be plotted in digital form

b. the part which utilizes the graphics system software to create the graph (Datagraphics 4460).

A modification of the above routine under the name subroutine PLOT is very useful in connection with the optimizing program.

Note: This set of subroutines utilizes the device characteristic subroutines and the short circuit program.

(e) COORDINATION OPTIMIZATION SUBROUTINES

These subroutines provide a computerized optimization procedure. The designer has to determine all the candidate settings which can be assumed by the system. The program calculates an overall coordination index for every combination of settings which yields the higher overall coordination index. The format of the required data is explained under the program FBBBOC.

The program FBBBOC refers to a system which includes a fuse and three breakers. This is the case of a typical substation at the Cape Kennedy Power System.

The program can be used as the basis for other programs which treat other cases, for example a substation implemented by a primary fuse and two breakers on the secondary. Actually this modification is offered as an option of the program FBBBOC.

2. DEVELOPMENT OF THE COORDINATION PROCEDURE

The following pages present the approach that has been taken to the coordination problem. This approach provides two main features:

(1) An algorithm which determines the optimum coordinated settings. The algorithm is employed in a computer program which determines the optimum coordinated settings

(2) A plotting routine which will graph on a common set of axes the characteristic curves of the protective devices employed by the system.

The optimizing algorithm applies to a radial distribution system such as the one at KSC. Looped systems are not considered.

2.1 REPRESENTATION OF DEVICE TIME VS. CURRENT CHARACTERISTICS

The first problem encountered in system protection coordination is how to reproduce the operating characteristics of the protective devices. Basically an approximation of the function

$$t = f(I)$$

is required.

To achieve this, it has proven practical to perform a coordinate transformation to a logarithmic scale as follows:

$$t' = C_1 \log t + C_1'$$

$$x = C_2 \log I + C_2'$$

where C_1 and C_2 constants serving normalization in such a way that

$$0 \leq t' \leq 1$$

$$0 \leq x \leq 1$$

In this case, the function $t = f(I)$ to be approximated becomes

$$t' = g(x), \quad (0 \leq x \leq 1), \quad (0 \leq t' \leq 1)$$

The scheme used to approximate the function

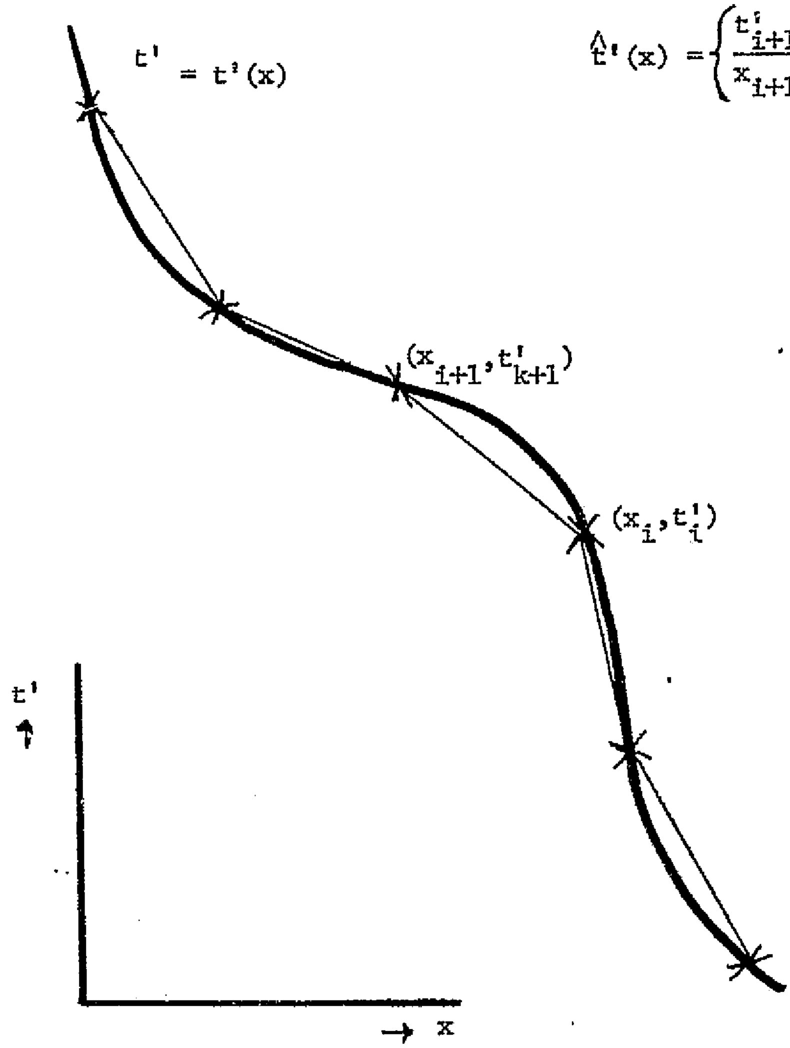
$$t' = g(x), \quad (0 \leq x \leq 1), \quad (0 \leq t' \leq 1)$$

is a piece-wise linear approximation of the curve; that is, the curve $t' = g(x)$ is approximated with pieces of straight line. This scheme is very simple and gives good accuracy. The accuracy depends on the number of line segments chosen; increasing as this number increases. For a typical breaker trip device curve, thirteen points give accuracy greater than 3%.

The following figure illustrates the method used. It should be clarified that in practice the points are chosen in a very dense mode where the curve is highly curved and in a dilute mode where the curve is close to a straight line. Some specifications define maximum clearing time curve and minimum clearing time curve. In this case, each curve is treated separately.

This approximation scheme provides the basis for the developed subroutines which are given in Appendix 1. Each subroutine can provide the maximum clearing time and the minimum tripping time of the corresponding protective device if the characteristics (settings or size) of the device and the current are determined. Subroutines are included for almost all devices employed in the KSC network.

APPROXIMATION SCHEME



$$\hat{t}'(x) = \left\{ \frac{t'_{i+1} - t'_i}{x_{i+1} - x_i} (x - x_{i+1}) + t'_{i+1} \quad \text{for } x_{i+1} < x < x_i \right\}$$

The above subroutines are used in the plotting program to graphically represent the characteristics of the devices which operate in a system under study. The characteristics are referred to a common current axis and then plotted. Details are explained in the plot routine.

Next probabilistic concepts of coordination which will be proven to be the analytic tool for an optimizing procedure are introduced.

2.2 OPERATIONAL CHARACTERISTICS OF DEVICES

In connection with the time-current characteristics of the devices, some operational factors are of importance in attempting to provide computer assistance to coordination. These pertain mainly to tolerance values on the specified operational curves. The specified time to trip for a certain level current is not a fixed value and varies due to a variety of reasons. This suggests that the time to trip of a device under sustained and fixed current level is distributed with some probability around the manufacturer's specified value. There are several contributions to this distribution. The following items include the most important effects:

1. Overtravel (applies to induction type relays).
2. The burden of the protective device circuit has an error of its own which introduces uncertainty about the value of the operating quantity (current or voltage).
3. The dead time (the time to clear the arc in the breaker) is not constant. Its duration depends on the condition of the breaker, the relative time to the cycle in which the arc starts, and breaker interrupting rating.
4. The fault current waveforms are usually distorted and therefore, the conditions of operation differ from those used for plotting

the time current curve.

5. Ambient temperature has a great influence especially on thermal trip unit devices. In this case, the thermal history of the system before the fault occurrence is significant.
6. Mechanical tolerances introduce an error especially on devices with movable parts and on filament type fuses.
7. Operator introduced error (important for devices with continuous settings).

In addition, the computer approximate representation scheme introduces an error.

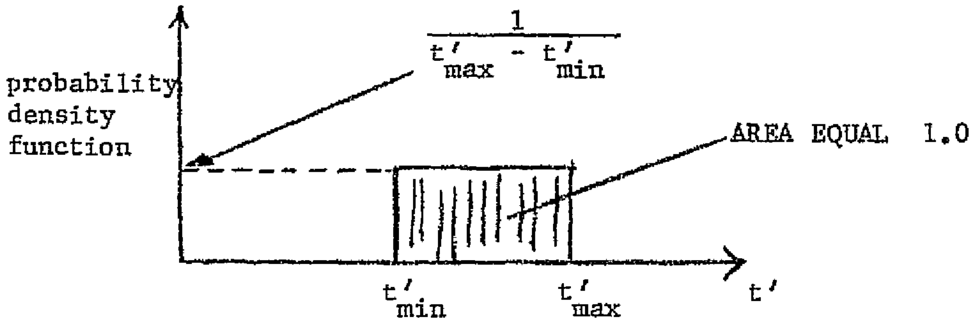
Most of these sources of error may be assumed to have Gaussian distribution. Assuming that each distribution has a standard deviation σ_i, then the total error will be Gaussian distributed with a standard deviation:

$$\sigma = \sqrt{\sum \sigma_i^2}$$

with summation over all applicable i.

The assumption of the Gaussian distribution is made with reference to the t' variable ($t' = C_1 \log t + C_1'$) which is in agreement with the mathematical requirement for the Gauss distribution to have a domain $-\infty < t' < \infty$. Note that the model is physically consistent since the time axis $o < t < \infty$ transformed to the t' axis becomes $-\infty < t' < \infty$.

The values of σ_i which apply for a given device are not all precisely known. Furthermore, the computational details connected with the Gaussian distribution are involved. Therefore it is practical to assume a less computationally involved distribution. As such the uniform probability distribution has been accepted. This distribution may be readily defined since the maximum and minimum tripping times are generally known. Using these the error distribution is determined as shown below.

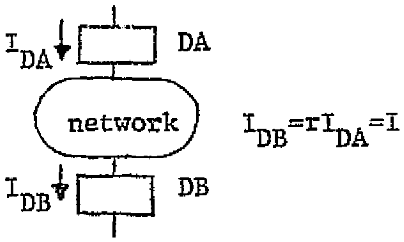


2.3 MEASURES OF COORDINATION

In order to utilize the computer to assess coordination between devices, it is necessary to define a quantitative measure of coordination to be used as a basis for comparison. These measures should provide in some sense an indication of the difference between interrupting times at a given current level of the devices being compared. As discussed previously, interruption time is regarded as a random number distributed in a uniform fashion about a nominal value. It therefore makes sense to develop a statistical measure to define coordination. In the following, the concept of coordination reliability is introduced. This is then extended to develop one additional index of coordination.

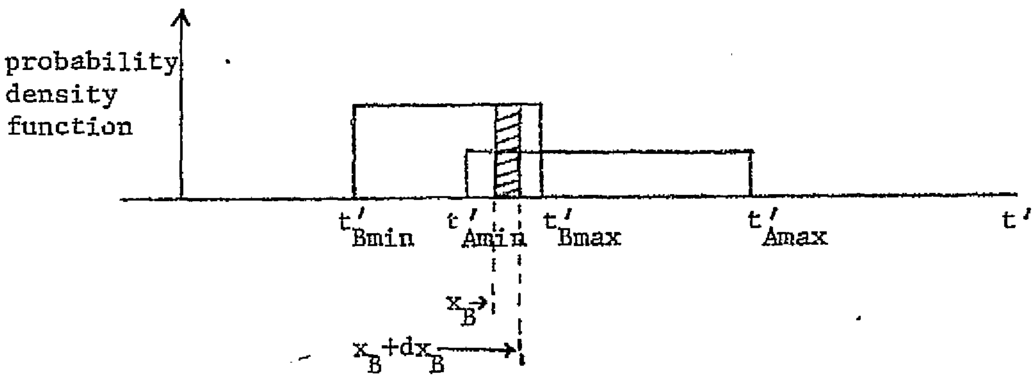
A. Reliability of Coordination

Consider a radial circuit with two protective elements DA and DB. Between them is an arbitrary network section which may or may not include transformers. In general, if I_{DB} is the current flowing through device DB, then $I_{DA} = I_{DB}/r$ is the current flowing in the device DA. Define r as the transformation ratio.



Suppose a fault current I through this radial is sustained until one of the devices trips. To assess coordination between DA and DB, it is necessary to know a priori which element interrupts first.

Assume that device specifications indicate that under sustained current I the interruption times for DA and DB are t'_{Amax}, t'_{Amin} for device DA, and t'_{Bmax}, t'_{Bmin} for device DB. According to the previous assumption of uniform distribution, the interruption times of the devices will then be distributed as:



Device DB will interrupt in the interval $(x_B, x_B + dx_B)$ with probability

$$dP_B = \frac{1}{t'_{Bmax} - t'_{Bmin}} \cdot dx_B \ .$$

Device DB will act first if device DA interrupts in any time x where $x > x_B$. The probability of this event is:

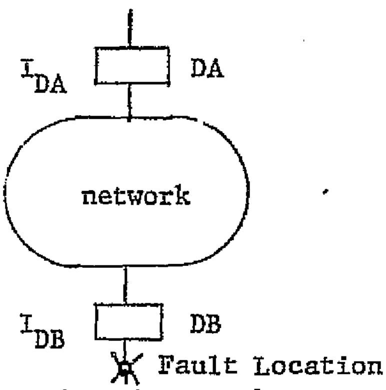
$$dP_{BA} = \begin{cases} \dfrac{1}{t'_{Bmax} - t'_{Bmin}} \, dx_B \cdot \dfrac{1}{t'_{Amax} - t'_{Amin}} \, (t'_{Amax} - x_B) & \text{if } x_B > t'_{Amin} \\[2ex] \dfrac{1}{t'_{Bmax} - t'_{Bmin}} \, dx_B & \text{if } x_B < t'_{Amin} \end{cases}$$

B. Expected Reliability of Coordination

Another important measure of system coordination relates to coordination on the average over the range of possible fault current levels.

The range of possible fault currents of a protective device is defined by the currents in the interval from the pickup value up to the short cicruit capacity at the point of application of the protective device.

Now consider the following situation. Along the radial there are two adjacent protective devices DA and DB, and between them there is an arbitrary network section.



At the position of the fault, the rated current is I_R and the short circuit capacity is I^{DB}_{Short}.

The device DB is set to trip if the current is greater than I^{DB}_{Pickup}. Similarly, for device DA we have I^{DA}_{Pickup}.

It is obvious that the common range of possible fault current for the two devices is

$$I^{DB}_{Pickup} < I_{DB} < I^{DB}_{Short}$$

For every current I_{DB} we can calculate, the reliability of coordination between the devices DA and DB, $R\ (I_{DB}, S_A, S_B, r)$.

Therefore, the probability that device DB will interrupt first is:

$$R = \int_{x_B = t'_{Bmin}}^{t'_{Bmax}} dP_{BA}$$

The probability number R is called the <u>reliability of coordination between devices DA and DB for the fault current I.</u>

This probability is a function of the current, and the specific settings of the devices,

$$R = R\ (I,\ S_A,\ S_B,\ r)$$

where S_A (S_B) represents the settings of the device DA (DB), and r is the transformation ratio.

It can be shown that:

$$R\ (I,\ S_A,\ S_B,\ r) = 1 - R\ (I,\ S_B,\ S_A,\ r).$$

It should be noted that this figure gives a measure of reliability at only a single level of fault current. One particular value of fault current for which the reliability index is significant is at the short circuit capacity of the associated line. This is due to the fact that for an underground cable system such as the system under consideration, most faults are expected to draw fault current near the short circuit capacity. The reliability index for this point is:

$$R_{S.C.} = R_{S.C.}(I_{S.C.},\ S_A,\ S_B,\ r)$$

This number then indicates coordination between elements DA and DB at one particular current value and is of great importance.

Then, on the average we will have

$$E[R\ (I_{DB},\ S_A,\ S_B,\ r)]$$

where the expectation extends over the common range of fault currents.

This measure of coordination is designated as A2. If the distribution of fault currents in the range of I_{DB}, $f\ (I_{DB})$ is known, then A2 may be computed explicitly as

$$A2 = \int_{\text{all } I_{DB}} R\ (I_{DB},\ S_A,\ S_B,\ r)\ f(I_{DB})\ dI_{DB}$$

The probability density distribution $f(I_{DB})$ is unfortunately not readily determined.

It has been determined, however, that in situations where the coordination is reasonably good, the measure A2 is not very sensitive to the specific distribution. It is therefore reasonable to make the simplifying assumption that fault currents in the range (I_{Pickup}, I_{Short}) occur equally likely. That is

$$f\ (I_{DB}) = \begin{cases} \dfrac{1}{I^{DB}_{Short} - I^{DB}_{Pickup}} , & I^{DB}_{Pickup} < I_{DB} < I^{DB}_{Short} \\ 0 , & \text{otherwise} \end{cases} .$$

Then

$$A2 = \frac{1}{I^{DB}_{Short} - I^{DB}_{Pickup}} \int_{I^{DB}_{Pickup}}^{I^{DB}_{Short}} R\ (I_{DB},\ S_A,\ S_B,\ r)\ dI_{DB}$$

Interpretation of A2 as a distance measure

The previously defined coordination measure A2 can also be interpreted as a measure of the relative position of the two curves.

$$t'_A = t'_A(I_{DA}) \qquad t'_B = t'_B(I_{DB})$$

For example, if A2 is very close to unity we can conclude that curve $t'_A = t'_A(I_{DA})$ is well above the cuve $t'_B = t'_B(I_{DB})$.

Guided by this interpretation a more rigorous measure of coordination may be developed. Suppose the minimum clearing time curve of device DA and the maximum clearing time curve of device DB are $t'_{\underset{min}{A}} = t'_{\underset{min}{A}}(I_{DA})$ and $t'_{\underset{max}{B}} = t'_{\underset{max}{B}}(I_{DB})$ respectively.

Another measure of coordination is then defined by the number A1 computed as

$$A1 = E[R((t'_{\underset{min}{A}}(I_{DA}) - t'_{\underset{max}{B}}(I_{DB})), S_A, S_B, r)]$$

where the expectation is taken in the same sense as for A2.

Obviously, if number A1 has a value close to one, the minimum clearing time curve of device DA is well above the maximum clearing time curve of device DB and therefore that coordination exists between the two devices.

Thus two different coordination measures are defined. The number A2 represents a physical quantity: It gives the probability of coordinated operation of the two devices over the entire operating current range. Its value provides information about possible overlaps of the associated time delay bands.

The number A1 describes the relative position between two curves. For example, if A1 = 1.0, it is concluded that the two curves never

intersect and the distance between them is everywhere greater than a prespecified value. Therefore, A1 is a stricter measure of coordination and can be considered as a safety factor.

2.4 COMPUTERIZED CALCULATION OF THE COORDINATION INDICES

The subroutines RELFUS, RELBRK, FUSBRK and BRKBRK given in Appendix 2 calculate the coordination indices A2, A1 and R_{sc} for the pairs of devices Relay-fuse, Relay-breaker, fuse-breaker and breaker-breaker respectively.

Each subroutine originally defines the set of all possible fault currents as it is described in the particular subroutine. Then it divides this set into NN intervals. It calculates the reliability of coordination in every part. Finally the coordination index is the sum of the calculated reliabilities weighted with the length of the corresponding interval.

The described procedure is applied for the indices A1 and A2. Last the reliability of coordination at the short circuit capacity RSC, is calculated.

2.4.1 Summary

In the preceeding text three coordination indices have been defined, A2, A1, and RSC. Their physical meaning is as follows:

A2: It assumes values between zero and one and represents an expectation of good coordination between two devices over a predefined range of fault currents. If its value is 1.0 it is to be concluded that the coordination is very good over the mentioned range of fault currents.

It is obvious that in a system where any kind of fault can occur with any value of fault impedance, the index A2 is very important. This is so, because under these conditions the level of the fault current can be anywhere above the load current of the system and below the bolted three phase or line to ground fault whichever is greater. The above statement should be modified accordingly if considerable asymmetry of fault currents is present. In other words, values of A2 near unity guarantee selectivity over the range of classified fault currents.

A1: It assumes values between 0 and 1.0, and represents a safety factor of good coordination between two devices over a predefined range of fault currents.

A1 expresses an average of safety factor over the mentioned range of fault currents. Therefore, values of A1 close to unity guarantee selectivity with a safety factor not only at one level of fault current but over all classified fault currents.

A comparison between A2 and A1 reveals that A1 is a stricter coordination index in the sense that if A1 = 1.0 then immediately A2 = 1.0. But if A2 = 1.0 then is not sure that A1=1.0.

A1 is a very useful index in characterizing the reliability of a system's selectivity. Or when uncertainty for the trip devices has been accumulated by the pass of time due to the lack of field tests.

RSC: It assumes values between 0.0 and 1.0 and expresses the reliability of coordination between two devices at the short circuit capacity of the system.

Unlike A1 and A2 it provides information at one and only one level of fault currents. The usefulness of this index is due to the fact that for some systems (e.g. underground cable or aerial cable) the levels of fault currents at a point of the system are confined with high probability in a rather narrow area just below the short circuit capacity of the system at that point. Given that the time vs current characteristics of the protective devices are smooth over wide intervals it can be concluded the RSC represents the coordination status of such systems with high probability.

Form the preceeding discussion it is obvious that each coordination index can be used for appropriately selected purpose of coordination, for example RSC can be used to assess coordination at the short circuit capacity of the system.

In general, for comparison purposes, it is expedient to express coordination with one number which will reflect all three defined coordination indices. The linear combination of A1, A2 and RSC has been adopted as follows:

$$RELOC = xA * A2 + xB * A1 + xC * RSC$$

$$\text{where } xA + xB + xC = 1.0$$

$$\text{and therefore } 0.0 \le RELOC \le 1.0 .$$

The coefficients xA, xB, and xC provide the flexibility to the designer to accomplish his own tendencies to the solution of the coordination problem by appropriately selecting the values of xA, xB, and xC. For example, suppose that designer A desires to have the protective devices coordinated at the short circuit capacity of the system. Then it is sufficient to select xA = 0, xB = 0, and xC = 1.0.

Now the number RELOC can be used as the comparison criterion between two different solutions to any coordination problem.

The above idea leads to the optimization algorithm. This algorithm will be presented for two devices:

Step 1: All the candidates settings of the devices/or devices are defined by the designer. The device which is supposed to trip first is specified. The short circuit capacity of the system at the point of application of the other device is calculated. Then reasonable range of possible fault currents is defined.

Step 2: Assume a solution i.e. devices and/or settings

Step 3: Compute A1, A2, and RSC for the above solution

Step 4: Compute RELOC = xA * A2 + xB * A1 + xC * RSC

Step 5: Register above solution as "optimum"

Step 6: Assume a different solution

Step 7: Compute A1, A2, and RSC for this solution

Step 8: Compute RELOC= xA * A2 + xB * A1 + xC * RSC

Step 9: Compare the two RELOC values. If second value is greater, register the current solution as "optimum." If first value is greater do not change the "optimum" solution. Finally keep the higher value of RELOC as comparison reference for the next comparison in this step.

Step 10: Assume another solution, different than the previous. Then go to Step 7. In case that all the candidate solution have been used, terminate the loop and go to the next step.

Step 11: Print out the currently registered "optimum" solution and relevant information.

The optimization program expands the above algorithm to more than two devices. The selected values of the coefficients xA, xB, and xC are: xA = .35, xB = .15, and xC = .50.

2.5 COMPUTERIZED PLOTTING

The development of the device characteristic subroutines makes easy the plotting of different characteristics of protective devices by the computer. The procedure is very simple. Suppose there are two devices A and B on a radial. Also, suppose a fault current I_B flows through device B. The time to operate t_B can be calculated by calling the appropriate subroutine of this device. Now when fault current I_B flows through device B, fault current I_A flows through device A. I_A can be computed with the current transformation ratio between these two devices. The time to operate t_A, of device A can be determined by calling the appropriate subroutine for this device. Now on the predefined common coordinate system, say t versus I_B the computer puts the points (t_B, I_B) and (t_A, I_B). The above procedure is repeated for many values of I_B over the range of possible fault currents I_B and finally a line is drawn through all the points (t_B, I_B) and another through all the points (t_A, I_B). Note that t_A (or t_B) can represent minimum operating time or maximum or their arithmetic mean.

A program has been developed which expands the described procedure to more than two devices.

Overlayed characteristics on a common coordinate system of the devices in a system is the best information about the coordination status of the devices. Therefore the plotting program can be used as a check to the output of the optimizing program (in fact the optimizing program

plots the optimum solution) or to evaluate by inspection any manually given solution to the coordination problem.

3. APPLICATIONS

In this section, application of the coordination and plotting programs are covered in detail. A specific example of application to a typical KSC substation configuration is examined initially. This example will illustrate the procedure for most existing KSC installations and a particular subroutine has been developed to treat this configuration (double fed substation with primary fuse, main secondary breaker, tie line breaker and feeder breakers). Following the example procedures necessary to accomodate alternative substation configurations are explained.

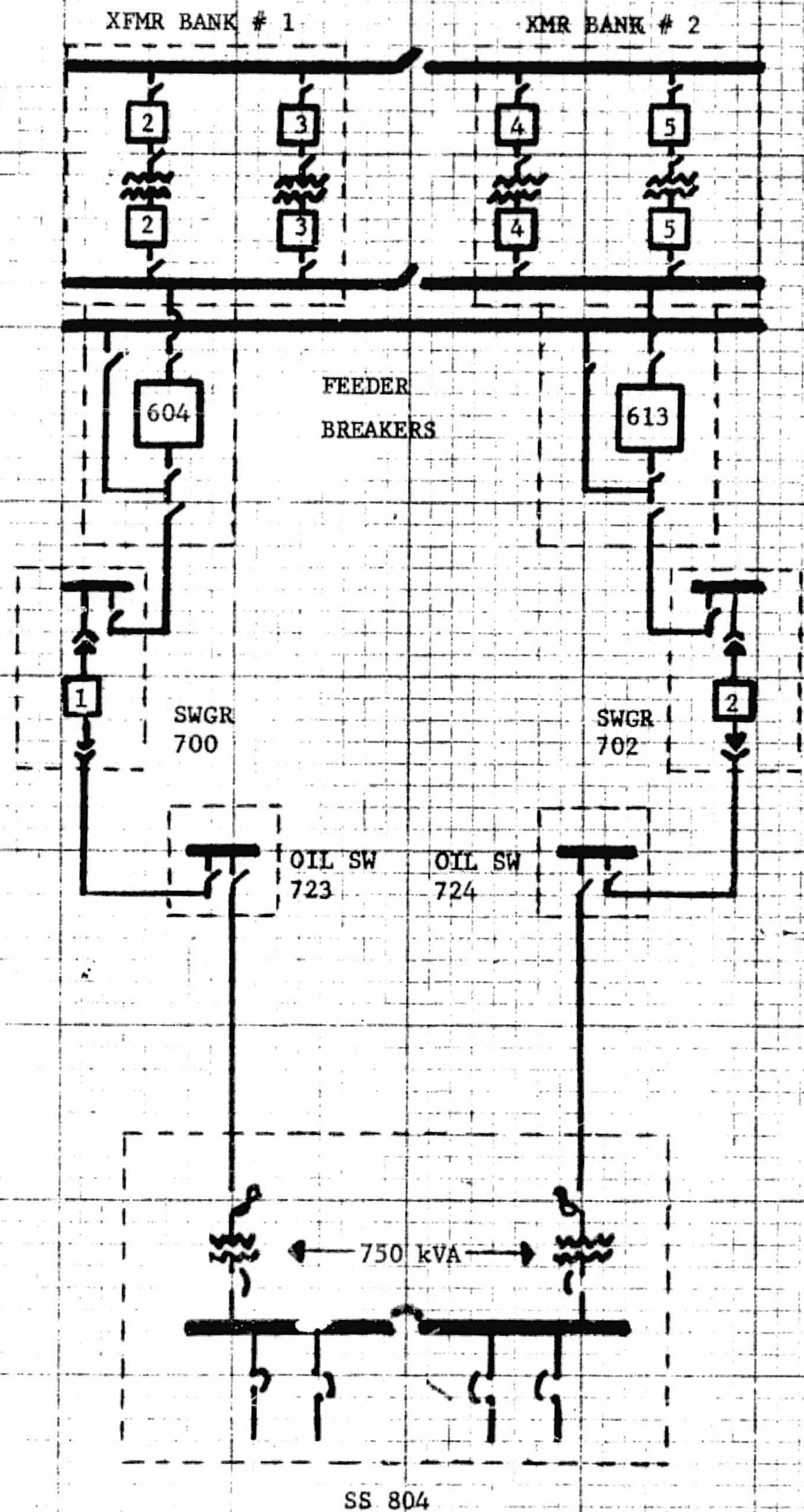
As an example, the coordination of the substation 804 located in the VAB is studied. This substation is a typical double fed substation in the system. The next figure shows the substation and its interconnection with the rest of the system.

The study is worked out in two steps:

a. Preparation of the data cards for the plotting program is carried out for the devices and settings as they exist. This results in a computer plot of the overlayed protective device characteristics. From the output the user can make an evaluation of the coordination status by inspection.

b. Preparation of the data cards for the optimizing program is carried out with comments which will be helpful for other cases.

The optimizing program also utilizes the plotting to provide



VAB SUBSTATION 804

a plot of the overlayed time vs current curves of the devices for the optimal settings.

3.1 USING THE PLOTTING ROUTINE

Use of the plotting routine is exemplified using substation 804 in the VAB. Data card preparation and output format are discussed.

The program has been designed to accomodate at most seven devices, 2 relays, 2 fuses and 3 breakers. The following identification names have been assigned to them: relay A, relay B, fuse A, fuse B, breaker A, breaker B, and breaker C.

The program requires eight data cards. The first one should contain general information about the system. The remaining seven correspond one to one to the seven devices. A missing device is identified by a blank card.

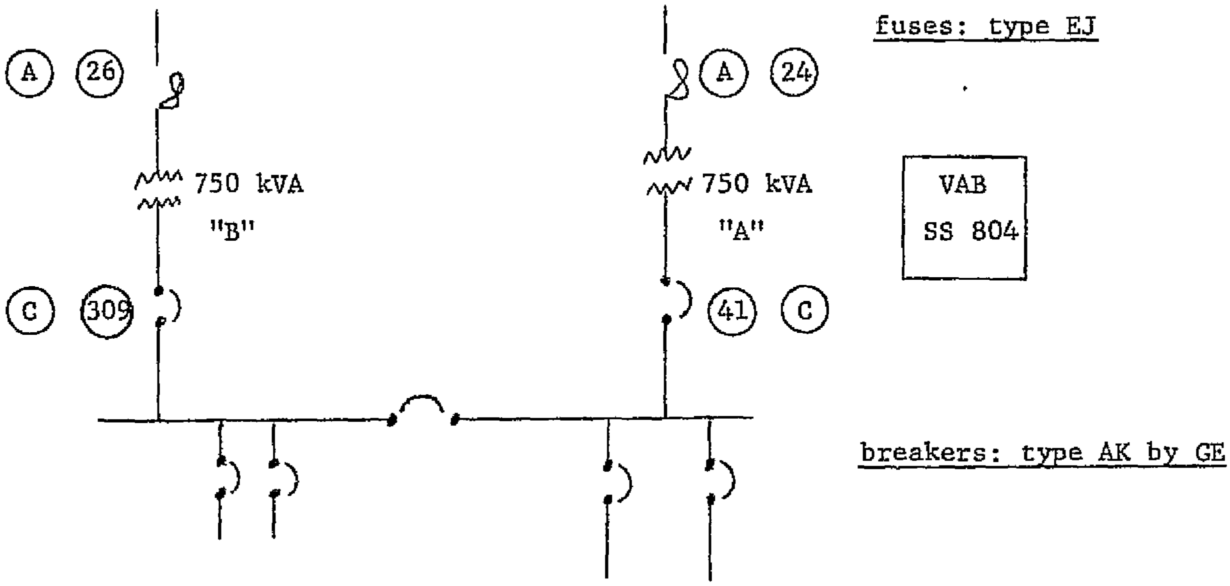
Preparation of data has been made under the following assumptions:

(1) Only fault currents are considered. The load current of interconnected lines and apparatus is ignored. Current transformation ratios are computed under this assumption

(2) The interrupting capacity of the breakers is assumed to be 20,000 Amperes. This is due to lack of information and should be modified accordingly when this information is available.

(3) Current transformation ratios that cannot be defined (for example between a non-existing device and another device) should be given the value 1.0.

It is desired to plot the characteristic curves of the protective devices in substation 804 located in the VAB.



This requires that the program plot the characteristic curves of the fuse (on the primary), of the main breaker, the tie line breaker and any one of the feeder breakers.

Therefore, data for one fuse and three breakers is required. The data cards for the relays A & B and fuse A should be blank.

Preceding all data cards the user should provide one card on which appears the title to appear on the plotted output.

1st data card

1-10	Current transformation ratio between relays A and B. (Relays A and B do not exist, therefore insert 1.0)
11-20	Current transformation ratio between relay B and fuse A. (Relay B and fuse A do not exist, therefore insert 1.0)
21-30	Current transformation ratio between fuse A and fuse B. (Fuse A does not exist, therefore insert 1.0)
31-40	Current transformation ratio between fuse and main breaker is 13,800/480 = 28.65
41-50	Current transformation ratio between main breaker; insert 1.0 and tie line (worst case)
51-60	Again insert (1.0) (worst case)

61	Insert 1 since substation 804 belongs to the Launch Complex 39 (Launch Complex 39 is record 1 on the network data tape used by the KSC short circuit program.)

<u>2nd data card</u>

blank (relay A does not exist)

<u>3rd data card</u>

blank (relay B does not exist)

<u>4th data card</u>

blank (fuse A does not exist)

<u>5th data card</u>

1-5	insert the symbolic name of the bus where the fuse is located, i.e. A24
6-10	insert <u>in column 10</u> the integer 1 since the fuse is of type EJO-1
11-15	the code for the size of the fuse. Size of the fuse 80E. From subroutine FUSEEJ the code for this size is 15. Therefore insert <u>in columns</u> 14 and 15 the number 15
16-25	the current rating of the fuse, i.e. 160.0

<u>6th data card</u>

1-5	insert the symbolic name of the bus where the main breaker is located; that is C41
6-15	the rated pickup current of the breaker, that is 1200.0
16-25	the interrupting capacity of the breaker. (Assumed to be 20000.00 amps.)

26-30	the code for the type of the breaker, that is 1 (breaker type AK)

To fill in the rest of this data card, reference must be made to subroutine BRKRAK

31-35	the code for the series trip device. Insert 1 (EC-1 series trip device)
36-40	code for the long time delay band. Max $\longrightarrow$ 3
41-45	code for the short time delay band. Intermediate $\longrightarrow$ 2
46-55	long time coil rating in per unit. In our case equals 1.20
56-65	short time pickup setting as a multiple of the rated pickup value. In our case 5.0

7th data card

The format is imilar to the 6th card. Insert the numbers corresponding to the tie line breaker as follows:

1-5	C41
6-15	1200.0
16-25	20000.0
26-30	1
31-35	1
36-40	3
41-45	2
46-55	0.8
56-65	2.5

8th data card

Select any one of the feeder breakers since each one is set in an identical way.

1-5	C41
6-15	300.0
16-25	20000.0
26-30	1
31-35	1
36-40	2
41-45	1
46-55	1.0
56-65	6.0

Output

The curves for the seven devices are plotted on a common scale. The lines are distinguished by the length and width of the dashes and by the numeric character printed on each point as follows:

Device	Number	Dash Length (rasters)	Line Width (rasters)
Relay A	1	solid	4
Relay B	2	solid	8
Fuse A (Upper)	3	32	2
(Lower)	3	32	4
Fuse B (Upper)	4	32	8
(Lower)	4	32	16
Breaker A (Upper)	5	64	2
(Lower)	5	64	4
Breaker B (Upper)	6	64	8
(Lower)	6	64	16
Breaker C (Upper)	7	256	2
(Lower)	7	256	4

3.2 USING THE OPTIMIZING ROUTINE

In this section the optimizing procedure is employed on Substation 804 in the VAB. The example outlines data preparation and procedures for applying the routine. The alternative substation configurations are given.

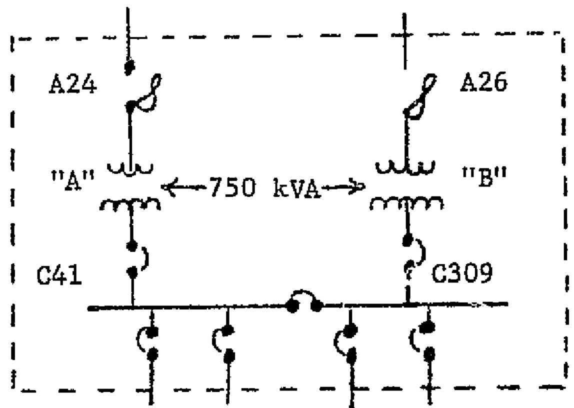
General Observation

The closest protective device to the substation is the breaker at the SWGR 700 (or SWGR 702 at the other side). Consideration is given to one side only (SWGR 700) since the other side is similar. The circuit 2 of the SWGR 700 which feeds transformer A in substation 804 is protected with an oil circuit breaker governed by an IAC relay. This circuit feeds a number of substations and therefore the relay's pickup current is well above the rated current of the transformer A in substation 804. The pickup current of the relay (circuit 2 at SWGR 700) is 480 amperes and the rated current of transformer A in substation 804 is 31.4 amperes. Under these conditions it is certain the coordination exists between the relay and any protective device in substation 804 (under the logical assumption that only one fault occurs in the system at a time).
and the rated current of transformer A in substation 804 is 31.4 amperes. Under these conditions it is certain that coordination exists between the relay and any protective device in substation 804.

Therefore it is necessary only to study coordination of the protective devices which are located in the substation and after it. In the case of the substation 804 it is required to determine coordination of the primary fuse, the main secondary breaker, the tie line breaker and the feeder breaker.

The Mathematical Model

The figure shows the substation and the symbolic names of the buses according to the model (short circuit study of the system)



Substation 804

The following analysis pertains to the side where transformer "A" is located. The other side is similar.

1. In the analysis presented here, the worst case of coordination is considered:

Suppose transformer B is out. Then, in order not to interrupt service at the load of the transformer B the tie line breaker has to close and the main secondary breaker of transformer B to open. In this case the following radial system exists: primary fuse - transformer "A" - main secondary breaker - tie line breaker - anyone of the feeder breakers on side "B".

Preparation of the data has been made under another assumption, i.e. load currents have been neglected. Therefore the current transformation ratios represent fault current transformation ratios.

Data Preparation

Step 1: Preparation of the data cards

Preceding all data cards the user should provide three cards in which he can punch anything he wishes to be the title of the program's output.

In this case a good title can be:

First card: SUBSTATION 804 LOCATED IN V.A.B

Second card: TRANSFORMER A SIDE

Third card: Blank

1. First card

Position	Insert	Explanation
1-6	A24	bus name at the location of the fuse
7-12	C41	bus name at the location of the main secondary breaker
13-18	C41	bus name at the location of the tie line breaker
19-24	C41	bus name at the location of the feeder breaker
25	0	since we do not have data on the overheating of the transformer (at the present time)
26	0	since the substation does not feed any motors.

Position	Insert	Explanation
27	1	The substion belongs to the Launch Complex 39. (Launch Complex 39 is record 1 on the network data tape used by the KSC short circuit program)
28	0	Double fed substation with primary fuse, main secondary breaker, tie line breaker and feeder breakers.

2. Second card

The interrupting capacities of the breakers are required. At the present time this information is not available. Therefore the value 20,000.00 in amperes is assumed:

Position	Insert
1-10	20000.0
11-20	20000.0
21-30	20000.0

3. Third card

Position	Insert	Explanation
1-10	28.65	$= \frac{13800}{480}$ = current transformation between fuse and main breaker
11-20	1.0	current transformation ratio between main breaker and tie line breaker.
21-30	1.0	current transformation ratio between tie line breaker and feeder breaker.
31-40	1200.0	rated pickup current in amperes of main secondary breaker
41-50	1200.0	rated pickup current in amperes of tie line breaker.

Position	Insert	Explanation
51-60	300.0	rated pickup current in amperes of feeder breaker. (Note: We usually choose the feeder with the higher normal load. In our case every feeder is designed for the same normal operation load.)

4. Fourth card

This card refers to the primary fuse which is of type EJO-1. Therefore subroutine FUSEEJ should be referenced

Position	Insert	Explanation
1-5	14	fuse type EJO-1, 65E, size DD
6-10	16	fuse type EJO-1, 100E, size DD
11-15	1	step of the do loop.

At the present time the primary fuse at the substation 804 is of type EJO-1, 80E, size DD. Looking at the corresponding subroutine (FUSEEJ) it is seen that three fuses of size DD are utilized, namely 65E, 80E, 100E with the codes 14, 15, 16 correspondingly. These three fuses can be interchanged without any change in the system. In order to nominate all three fuses as candidates insert the number 14, 16 and 1 as has been described.

Suppose it is desired to retain the fuse 80E in the system. Then insert 15 in the two positions: 1-5 and 6-10 and leave everything else as it is.

Position	Insert	Explanation
16-20	1	the code for the subroutine FUSEEJ is 1.

5. Fifth card

This card refers to the main secondary breaker which is of type AK. Therefore subroutine BRKRAK should be referenced.

Position	Insert	Explanation
1-5 6-10 11-15	1 1 1	the main secondary breaker is of type AK with EC-1 series trip device. Looking at the subroutine BRKRAK it is seen that the code for the EC-1 series trip device is 1. Furthermore it is not desired to change the series trip device. So the program is instructed to consider the series trip device with code 1 that is EC-1.
16-20 21-25 26-30	1 3 1	code for the long time delay band. The program will consider the minimum band (code 1), the intermediate band (code 2) and the maximum band (code 3). For the interpretation of the code see subroutine BRKRAK
31-35 36-40 41-45	1 3 1	code for the short time delay band. Same comments as for the long time delay band can apply.
46-50 51-55 56-60	80 120 20	the long time coil rating expressed in percent. We want the computer to consider the settings between 80% and 120% with step of 20% that is the settings 80%, 100% and 120%.

Position	Insert	Explanation
61-65	3	short time pickup current. From the manufacturer data it can be seen that the short time pickup current can take any value between 2 and 5 times the rated pickup current of the unit. Here the computer is to consider all the values between 3 and 5 times the rated pickup current (i.e. 1200.0 amperes) proceeding with step 1. In other words the following values 3, 4 and 5 times the rated pickup current.
66-70	5	
71-75	1	
76-80	1	code for the breaker type AK. The code refers to the subroutine BRKRAK.

6. Sixth card

Position	Insert	Explanation
1-5	1	
6-10	1	EC-1 series trip device
11-15	1	
16-20	1	
21-25	3	minimum-intermediate and maximum long time delay band.
26-30	1	
31-35	1	
36-40	3	minimum-intermediate and maximum short time delay band.
41-45	1	

Position	Insert	Explanation
46-50	80	
51-55	120	80%, 100% and 120% long time coil rating
56-60	20	
61-65	2	
66-70	4	2, 3 and 4 (times the rated pickup current) short time pickup settings
71-75	1	
76-80	1	breaker type AK and therefore subroutine BRKRAK.

7. Seventh card

This card refers to the feeder breaker No. ICB4 - 10CLA which is an AK-2A-25 breaker. Therefore the subroutine BRKRAK should be referenced. Preparation of data and explanation is similar as per the fifth data card.

Position	Insert	Explanation
1-5	1	
6-10	1	EC-1 series trip device
11-15		
16-20	1	
21-25	3	minimum, intermediate and maximum long time delay band
26-30	1	
31-35	1	
36-40	3	minimum, intermediate and maximum short time delay band.
41-45	1	

Position	Insert	Explanation
46-50	100	We desire to keep the rating of the long time coil fixed at 100 percent.
51-55	100	
56-60	20	
61-65	4	from the manufacturers data it is seen that the short time pickup current can be any number between 4 and 10 times the rated pickup current. Therefore the computer is to consider only the settings 4, 5, 6, 7 and 8.
66-70	8	
71-75	1	
76-80	1	type AK breaker.

8. Eighth card

Position	Insert	Explanation
1-4	PLOT	The word "PLOT" here causes the optimal coordination curves to be plotted by the computer. This card is omitted if no plot is desired.

NOTES

1. When an integer number is to be punched in a certain position bear in mind that the computer will interpret a blank space as zero. Therefore when it is required to punch the integer 14 in the columns 1 through 5, a1 should be punched in column 4 and 4 in column 5.

2. The program can handle as well single fed substations which are implemented with primary fuse, main secondary breaker and feeder breakers. This is offered as an option.

Implementation of the above modification (option) is achieved by punching a one in column 28 of the first data card. In this case the computer skips the part which refers to the second breaker and the optimizing algorithm applies to the fuse and two breakers only. For practical purposes (to avoid warnings) the data card which refers to the second breaker should be identical to the data card which refers to the first breaker. Finally any output referring to the second breaker (breaker B) should be ignored.

PART II. Appendices.

INDEX OF SUBROUTINES

Appendix I.

Symbolic name	Description	Page
RELIAC	simulates the characteristics of relays type IAC by G.E.	
RELACO	simulates the characteristics of relays type CO by Westinghouse	
BRKRAK	simulates the characteristics of breakers type AK by G.E.	
BRKRLA	simulates the characteristics of breakers type LA by Allis-Chalmers	
BRKROD	simulates the characteristics of breakers type OD by I.T.E.	
BRKRDB	simulates the characteristics of breakers type DB by Westinghouse	
MCCBGE	simulates the characteristics of molded case circuit breakers by G.E.	
FUSEEJ	simulates the curves of fuses type EJ-1, EJO-1 and EJ-2 by G.E.	
FUSCLE	simulates the curves for fuses type CLE-1 and CLE-2 by Westinghouse	
FUSECL	simulates the curves of fuses type CL-13 by I.T.E.	
FUSESM	simulates the curves of fuses type SM by S & C Electric Company	
FUNCTN	simulates a piecewise linear function defined by N points ($2 \le N \le 20$).	

Appendix 2

Symbolic name	Description	Page
FUSBRK	computes the coordination indices A1, A2 and RSC between any fuse and any breaker existing in Appendix 1.	
BRKBKR	computes the coorindation indices A1, A2 and RSC between any two breakers existing in Appendix 1.	
RELBRK	computes the coordination indices A1, A2 and RSC between any relay and any breaker existing in Appendix 1.	
RELFUS	computes the coordination indices A1, A2 and RSC between any relay and any fuse existing in Appendix 1.	

Appendix 3

Symbolic name	Description	Page
CHECKH	it checks if a prespecified fuse (from the existing in Appendix 1) clears any fault before any damage can happen to the system due to heat dissipation	
CHECHS	it checks if a prespecified breaker (from the existing in Appendix 1) does not operate when an inrush motor starting current occurs in the system.	

APPENDIX 1

DEVICE CHARACTERISTICS SUBROUTINES

These subroutines simulate the time vs current characteristics of the protective devices employed in the Kennedy Space Center power system. The piecewise linear approximation of a curve is generally used. Each curve is defined with a number of points which differs from case to case. The appropriate characteristic is determined with minimum device parameters.

The subroutines can be used in two ways:

A. To return the operating time of the device at a given current, and

B. To retrieve the time vs current characteristic of the device for predetermined settings.

SUBROUTINE RELIAC

SUBROUTINE RELIAC

General Description

RELIAC is a FORTRAN subroutine which returns the time required by a relay type IAC of General Electric to close a tripping circuit when the settings of the relay and the current are specified.

Calling Sequence

```
CALL RELIAC(XR,NTCHR,TDS,YR)
```

where

XR is the value of current expressed in multiples of the pickup value.

NTCHR is a code for the type of the time characteristic curve and assumes integer values as follows:

NTCHR = 1	=	inverse time characteristic
2	=	very inverse time characteristic
3	=	extremely inverse time characteristic
4	=	inverse, short-time characteristic
5	=	inverse, long-time characteristic

TDS is the time dial settings and assumes real values in the field (.5 - 10.)

YR is the variable which will assume the value of the time to close the tripping circuit in the transformed system of coordinates. Therefore, the same time in seconds will be:

time to close the tripping circuit = .01*(10.0**(5.0*YR))

Comments

For each family of curves (for example very inverse time characteristic), the curves corresponding to the time dial settings .5, 4.0, and 10.0 have been stored (with 13 points each) under the symbolic names (XC,YB), and (XC,YC) respectively.

Analytically:

$$\left.\begin{array}{ll} (XC(K),YA(I)), & TDS = .5 \\ (XC(K),YB(I)), & TDS = 4. \\ (XC(K),YC(I)), & TDS = 10. \end{array}\right\} \qquad K = 1,13$$

I = 1,13 = inverse time characteristic

I = 14,26 = very inverse time characteristic

I = 27,39 = extremely inverse time characteristic

I = 40,52 = inverse, short-time characteristic

I = 53,65 = inverse, long-time characteristic

Curves for other time dial setting are approximated by interpolation.

Other Subroutines Used

FUNCTN

SUBROUTINE RELACO

SUBROUTINE RELACO

General Description

RELACO is a FORTRAN subroutine which returns the time required by a relay type CO of Westinghouse to close a tripping circuit when the settings of the relay and the current are specified.

Calling Sequence

CALL RELACO(XR,NTCHR,TDS,YR)

where

XR is the value of the current expressed in multiples of the pickup value.

NTCHR is a code for the type of the relay and assumes integer values as follows:

NTCHR = 1	type CO-2
2	type CO-5
3	type CO-6
4	type CO-7
5	type CO-8
6	type CO-9
7	type CO-11

TDS is the dial setting and assumes real values in the field (0.5 - 11.0)

YR is the variable which will assume the value of the time to close the tripping circuit in the transformed system of coordinates. Therefore, the same time in seconds will be:

time to close the tripping circuit =.01*(10.0**(5.0*YR))

Comments

For each type of curves, (for example curves CO-5), the curves corresponding to the time dial settings .5, 4.0, and 11.0 have been stored (with 13 points each) under the symbolic names (XC,YA), (XC,YB), and (XC,YC) respectively.

Specifically:

(XC(K),YA(I)),	TDS = .5	
(XC(K),YB(I)),	TDS = 4.0	K = 1,13
(XC(K),YC(I)),	TDS = 11.0	

I = 1,13 = type CO-2
I = 14,26 = type CO-5
I = 27,39 = type CO-6
I = 40,52 = type CO-7
I = 53-65 = type CO-8
I = 66-78 = type CO-9
I = 79-91 = type. CO-11

Curves for other time dial settings are approximated by interpolation.

Other Subroutine Used

FUNCTN

SUBROUTINE FUSECL

SUBROUTINE FUSECL

General Description

FUSECL is a FORTRAN subroutine which returns the total clearing time and the minimum melting time of any fuse type CL-13 current-limiting, 14.4 Kv by I-T-E Imperial Corporation, given the current.

Calling Sequence

CALL FUSECL (XFUSE, YFUSEU, YFUSEL, NFUSE)

where

XFUSE is the current in amperes

YFUSEU is the variable which will assume the total clearing time of the fuse in the transformed system of coordinates. Therefore, the total clearing time in seconds will be:

Total clearing time (sec) = .01*(10.**(5.*YFUSEU))

YFUSEL is the variable which will assume the minimum melting time of the fuse in the transformed system of coordinates. Therefore, the minimum melting time in seconds will be:

Minimum melting time (sec) = .01*(10.**(5.0*YFUSEL))

NFUSE is the code for the particular fuse we are interested in. The following table explains the selection of this entry:

Type CL-13 current-limiting fuse units voltage rating 14.4 Kv

Reference: I-T-E Imperial Corporation

No. CL-13-4	Date Feb. 20, 1969	Rev. 3

NFUSE	1	2	3	4	5	6	7	8	9	10	11	12	13
FUSE SIZE	10E	15E	20E	25E	30E	40E	50E	65E	80E	100E	125E	150E	200E

Comments

Total clearing time-current characteristic curves are stored with 8 points for each curve. The minimum melting time is determined by taking into account a -15% tolerance in terms of the current of the stored curves. That is to find the minimum melting time-current curve, the total clearing time-current curve is shifted to the left by a distance corresponding to 15 percent.

Other Subroutines Used

FUNCTN

SUBROUTINE FUSCLE

SUBROUTINE FUSCLE

General Description

FUSCLE is a FORTRAN subroutine which returns the total clearing time and the minimum melting time of any fuse type CLE-1 and CLE-2, 14.4 Kv by Westinghouse Electric Corporation, given the current.

Calling Sequence

CALL FUSCLE (XFUSE, YFUSEU, YFUSEL, NFUSE)

where

XFUSE is the current in amperes

YFUSEU is the variable which will assume the total clearing time of the fuse in the transformed system of coordinates. Therefore, the total clearing time in seconds will be

Total clearing time (sec) = .01*(10.**(5.*YFUSEU))

YFUSEL is the variable which will assume the minimum melting time of the fuse in the transformed system of coordinates. Therefore, the minimum melting time in seconds will be

Minimum melting time (sec) =.01*(10.**(5.0*YFUSEL))

NFUSE is the code for the particular fuse we are interested in. The following table explains the selection of this entry

Type CLE-1 and CLE-2 current limiting power fuses, 14.4 Kv by Westinghouse

References: Curve No. 14
and Curve No. 15

Reference No. 598783, 598784, 622124, 622129

NFUSE	1	2	3	4	5	6	7	8	9
FUSE SIZE	30E	40E	50E	65E	80E	100E	125X	150E	175E/200X

Comments

Both minimum melting time-current and total clearing time-current characteristic curves are stored with 13 points for each curve. In calculating the minimum melting time, a safety band is taken into account. It is achieved by shifting to the right the value of the current by an appropriate amount (.05 in the transformed current axis).

Other Subroutines Used

FUNCTN

SUBROUTINE FUSESM

SUBROUTINE FUSESM

General Description

FUSESM is a FORTRAN subroutine which returns the total clearing time and the minimum melting time of any fuse type SM by S & C Electric Company, given the current.

Calling Sequence

CALL FUSESM(XFUSE,YFUSEU,YFUSEL,NFUSE)

where

XFUSE is the current amperes

YFUSEU is the variable which will assume the total clearing time of the fuse in the transformed system of coordinates. Therefore, the total clearing time in seconds will be

Total clearing time = .01*(10.**(5.0*YFUSEU))

YFUSEL is the variable which will assume the minimum melting time of the fuse in the transformed system of coordinates. Therefore, the minimum melting time in seconds will be

Minimum melting time = .01*(10.**(5.0*YFUSEL))

NFUSE is the code for the particular fuse we are interested in. The following table explains the selection of this entry

I. SM Refill units - SLOW SPEED
Reference: S & C publication:

	Page 1 of 1
TCC NUMBER	119-4
	July 19, 1969

NFUSE assumes values 1 through 19 as follows:

NFUSE	1	2	3	4	5	6	7	8	9	10
FUSE SIZE	15E	20E	25E	30E	40E	50E	65E	80E	100E	125E

NFUSE	11	12	13	14	15	16	17	18	19
FUSE SIZE	150E	175E	200E	250E	300E	400E	2-250E	2-300E	2-400E

II. SM Refill units - STANDARD SPEED
Reference: S & C publication:

	Page 1 of 1
TCC NUMBER	153-4
	July 21, 1969

NFUSE assumes values 20 through 43 as follows:

NFUSE	20	21	22	23	24	25	26	27	28	29	30	31
FUSE SIZE	3E	5E	7E	10E	13E	15E	20E	25E	30E	40E	50E	65E

32	33	34	35	36	37	38	39	40	41	42	43
80E	100E	125E	150E	175E	200E	250E	300E	400E	2-250E	2-300E	2-400E

Comments

Only the minimum melting time - current characteristic curves of the fuses are stored with ten points for each curve. Maximum clearing time - current characteristic curves are determined by shifting the stored curves parallel to the current axis at a distance equal to the manufacturer's specified tolerance.

Other Subroutines Used

FUNCTN

SUBROUTINE FUSEEJ

SUBROUTINE FUSEEJ

General Description

FUSEEJ is a FORTRAN subroutine which returns the total clearing time and the minimum melting time of any fuse type EJ by General Electric, given the current.

Calling Sequence

```
CALL FUSEEJ (XFUSE, YFUSEU, YFUSEL, NFUSE)
```

where

XFUSE is the current in amperes

YFUSEU is the variable which will assume the total clearing time of the fuse in the transformed system of coordinates. Therefore, the total clearing time in seconds will be

Total clearing time (sec) = .01*(10.**(5.*YFUSEU))

YFUSEL is the variable which will assume the minimum melting time of the fuse in the transformed system of coordinates. Therefore, the minimum melting time in seconds will be

Minimum melting time (sec) = .01*(10.**(5.0*YFUSEL))

NFUSE is the code for the particular fuse we are interested in. The following table explains the selection of this entry:

I. CURRENT - LIMITING POWER FUSE

EJ-1 & EJO-1 14.4 Kv

References: GES-8104
GES-8105

NFUSE assumes values 1 through 9 as follows:

NFUSE	1	2	3	4	5	6	7	8	9	10	11	12	13
FUSE SIZE	.5E	1E	2E	3E	5E	7E	10E	15E	20E	25E	30E	40E	50E
	SIZE C							SIZE D					

14	15	16	17	18	19
65E	80E	100E	125	150	175
SIZE DD			SIZE EE		

II. CURRENT - LIMITING POWER FUSE

EJ-2 2.4 & 4.8 Kv

References: GES-8100A

GES-8101A

NFUSE assumes values 20 through 29 as follows:

NFUSE	20	21	22	23	24	25	26	27	28	29
FUSE SIZE	2R	3R	4R	6R	9R	12R	18R	24R	30R	36R

Comments

Both minimum melting time-current and total clearing time-current characteristic curves are stored with eleven points for each curve.

Other Subroutines Used

FUNCTN

SUBROUTINE BRKRDB

SUBROUTINE BRKRDB

General Description

BRKRDB is a FORTRAN subroutine which returns the maximum tripping time and the minimum tripping time of any breaker type DB by Westinghouse, given the current as a multiple of the pickup current. The subroutine does not include special features as "long delay 25-150 seconds."

Calling Sequence

CALL BRKRDB (NSTD, NLTDB, NSTDB, XLTCR, XSTS, XBR, YUPPER, YLOWER)

where

NSTD is the code for the particular breaker we are interested in. NSTD assumes values 1, 2, 3 as follows:

NSTD	1	2	3
BREAKER	DB-15 or DB-25	DB-50	DB-75 or DB-100

NLTDB is the long delay setting which should assume integer values in the interval (20, 30). Once again, the subroutine features only long delay setting adjustable with calibrated marks at 30 and 20 seconds.

NSTDB is the short delay setting adjustable with calibrated marks at 30, 14, and 6 cycles or instantaneous. It assumes integer values 0, 1, 2, 3 as follows:

NSTDB	0	1	2	3
Short delay setting	Instantaneous	6 cycles	14 cycles	30 cycles

XLTCR is the long delay pickup setting adjustable with calibrated marks at 80, 100, 120, 140, and 160 percent of trip unit rating. It assumes real values .8, 1., 1.2, 1.4, and 1.6 as follows:

XLTCR	.80	1.00	1.20	1.40	1.60
Long delay pickup setting	80%	100%	120%	140%	160%

XSTS is the instantaneous pickup setting or the short delay pickup setting as a multiple of the trip unit rating. This entry assumes a real value.

XBR is the current in multiples of the trip unit rating. It is a real number.

YUPPER is the variable which will assume the maximum tripping time in the transformed system of coordinates. Therefore, the maximum tripping time in seconds will be:

Maximum tripping time (sec) = .01*(10.0**(5.0*YUPPER))

YLOWER is the variable which will assume the minimum tripping time in the transformed system of coordinates. Therefore, the minimum tripping time in seconds will be:

Minimum tripping time (sec) = .01*(10.0**(5.0*YLOWER))

Comments

Data are stored in the subroutine as follows:

Total clearing time	Minimum tripping time
(XU(I), YU(I))	XL(I), YL(I)

I=1,9 DB-15 or DB-25
long delay at 100% pickup and 30 seconds long delay setting

I=10,15 DB-15 or DB-25
short delay 6 cycles

I=16,21 DB-15 or DB-25
short delay 14 cycles

I=22,27 DB-15 or DB-25
short delay 30 cycles

I=28,36 DB-50
long delay at 100% pickup and 30 seconds long delay setting

I=37,42 DB-50
short delay 6 cycles

I=43,48 DB-50
short delay 14 cycles

I=49,54 DB-50
short delay 30 cycles

I=55,63 DB-75 or DB-100
long delay at 100% pickup and 30 seconds long delay setting

I=64,69 DB-75 or DB-100
short delay 6 cycles

I=70,75 DB-75 or DB-100
short delay 14 cycles

I=76,81 DB-75 or DB-100
short delay 30 cycles

Instantaneous

Total clearing time

(XIU(I), YIU(I))

I=1,7 DB-15 or DB-25

I=8,14 DB-50

I=15,21 DB-75 or DB-100

Other Subroutines Used

FUNCTN

SUBROUTINE BRKRAK

SUBROUTINE BRKRAK

General Description

BRKRAK is a FORTRAN subroutine which returns the maximum and the minimum tripping time of any breaker type AK equipped with a series trip device EC-1B or EC-1 given the current as a multiple of the rated pickup current.

Calling Sequence

CALL BRKRAK(NSTD, NLTDB, NSTDB, XLTCR, XBR, YUPPER, YLOWER)

where

NSTD is the code for the particular series trip device we are interested in. NSTD assumes integer values 1 or 2 as follows:

NSTD	1	2
Series trip device	EC-1	EC-1B

NLTDB is the code for the long delay setting which can assume integer values 1, 2, or 3 as follows:

NLTDB	1	2	3
Long time delay band	Minimum	Intermediate	Maximum

NSTDB is the short time delay setting which assumes integer values 1, 2, or 3 as follows:

NSTDB	1	2	3
Short time delay band	Minimum	Intermediate	Maximum

XLTCR is the long time coil rating in per unit of the rated pickup current. This entry assumes a real value.

XSTS is the short time delay pickup setting expressed in multiples of the trip unit rating. This entry assumes a real value

YUPPER is the variable which will assume the maximum tripping time in the transformed system of coordinates. Therefore, the maximum tripping time in seconds will be:

Maximum tripping time (sec) = .01*(10.0**(5.0*YUPPER))

YLOWER is the variable which will assume the minimum tripping time in the transformed system of coordinates. Therefore, the minimum tripping time in seconds will be:

Minimum tripping time (sec) = .01*(10.0**(5.0*YLOWER))

Comments

Data stored in the subroutine are as follows:

Total clearing time

XB(I), YB(I)

Minimum tripping time

XA(I), YA(I)

where

I = 1,13	series trip device EC-1 @ Minimum long time delay @ Minimum short time delay
I = 14,26	series trip device EC-1 @ Intermediate long time delay @ Intermediate short time delay
I = 27,39	series trip device EC-1 @ Maximum long time delay @ Maximum short time delay.

I = 40,52	series trip device EC-1B
	@ Minimum long time delay
	@ Minimum short time delay
I = 53,65	series trip device EC-1B
	@ Intermediate long time delay
	@ Intermediate short time delay
I = 66,78	series trip device EC-1B
	@ Maximum long time delay
	@ Maximum short time delay

Other Subroutines Used

FUNCTN

SUBROUTINE BRKRLA

SUBROUTINE BRKRLA

General Description

BRKRLA is a FORTRAN subroutine which returns the maximum and the minimum tripping time of any breaker type LA equipped with a trip device Model D or Model A by Allis-Chalmers, given the current as a multiple of the pickup current.

Calling Sequence

CALL BRKRLA (NSTD, NLTDB, NSTDB, XLTCR, XSTS, XBR, YUPPER, YLOWER)

where

NSTD is the code for the particular trip device we are interested in. NSTD assumes integer values 1 or 2 as follows:

NSTD	1	2
TRIP DEVICE	Model D or DG	Model A or AG

NLTDB is the long delay setting which should assume integer values 1, 2, or 3 as follows:

NLTDB	1	2	3
Long time band	Minimum	Intermediate	Maximum

NSTDB is the short delay setting which assumes integer values 1, 2, or 3 as follows:

NLTDB	1	2	3
Short time band	Minimum	Intermediate	Maximum

This entry applies only to the Model D. In case of the Model A, this entry can assume any integer value without affecting anything.

XLTCR does not apply in the present subroutine. Set XLTCR = 1.0.

XSTS is the instantaneous pickup setting or the short delay pickup setting as a multiple of the trip unit rating. This entry assumes a real value.

XBR is the current in multiples of the trip unit rating. It is a real number.

YUPPER is the variable which will assume the maximum tripping time in the transformed system of coordinates. Therefore, the maximum tripping time in seconds will be:

Maximum tripping time (sec) = .01*(10.0**(5.0*YUPPER))

YLOWER is the variable which will assume the minimum tripping time in the transformed system of coordinates. Therefore, the minimum tripping time in seconds will be:

Minimum tripping time (sec) = .01*(10.0**(5.0*YLOWER))

Comments

Data stored in the subroutine are as follows:

Total clearing time

(XU(K), YU(I)), K=1,9

Minimum tripping time

(XL(L), YL(N)), L=1,10

where

I = 1,9 N = 1,10	Model D, minimum long time band
I = 10,18 N = 11,20	Model D, intermediate long time band
I = 19,27 N = 21,30	Model D, maximum long time band

I = 28,36 N = 31,40	Model A, minimum long time band
I = 37,45 N = 41,50	Model A, intermediate long time band
I = 46,54 N = 51,60	Model A, maximum long time band

Total clearing time

XIU(I), YIU(I)

I = 1,5	Model A, instantaneous tripping
YIDL(1) YIDU(1)	Model D, minimum short time band
YIDL(2) YIDU(2)	Model D, intermediate short time band
YIDL(3) YIDU(3)	Model D, maximum short time band

Other Subroutines Used

FUNCTN

SUBROUTINE MCCBGE

SUBROUTINE MCCBGE

General Description

MCCBGE is a FORTRAN subroutine which returns the maximum tripping time and the minimum tripping time of Molded Case Circuit Breakers by General Electric (namely E100 line, F225 line, J600 line and K1200 line), given the current as a multiple of the pickup current.

Calling Sequence

CALL MCCBGE (NSTD, NLTDB, NSTDB, XLTCR, XSTS, XBR, YUPPER, YLOWER)

where

NSTD is the code of the particular breaker we are interested in. NSTD assumes values 1 through 14. The selection of this entry is explained in note 1.

NLTDB is the entry which refers to the temperature compensation. It assumes the value 1 if the breaker is enclosure compensated; 2 if the breaker is ambient compensated.

NSTDB This entry does not apply to the present subroutine. It is kept, however, in order to have the same format for all the breaker subroutines. Give the value 1 to this entry.

XLTCR is the ambient temperature in (^{o}C). In cases where there is difficulty in estimating the ambient temperature, set XLTCR equal to 40.0.

XSTS is the setting for the instantaneous trip unit and applies in the case of the breakers F225, J600, and K1200 only. The possible values of this entry appear in note 1.

In case of breaker E100, set XSTS equal to 1.

XBR is the current in multiples of the pickup current.

YUPPER is the variable which will assume the maximum tripping time in the transformed system of coordinates. Therefore, the maximum tripping time in seconds will be:

Maximum tripping time (sec) = .01*(10.0**(5.0*YUPPER))

YLOWER is the variable which will assume the minimum tripping time in the transformed system of coordinates. Therefore, the minimum tripping time in seconds will be:

Minimum tripping time (sec) = .01*(10.0**(5.0*YLOWER))

Note 1:

I. E100 line by General Electric

The entry NSTD assumes the following values:

Types TEB, TED, and THED

NSTD = 1 when the current rating is 15-45 amperes
= 2 when the current rating is 50-80 amperes
= 3 when the current rating is 90 & 100 amperes

Types TEF & THEF (enclosure compensated)

NSTD = 4 when the current rating is 10-45 amperes
= 5 when the current rating is 50-100 amperes

Types TEF & THEF (ambient compensated)

NSTD = 6 when the current rating is 15-40 amperes
= 7 when the current rating is 50-100 amperes

II. F225 line, J600 line, K1200 line by General Electric

The entry NSTD assumes values as follows:

F225

NSTD	current rating (in amperes)	possible values of the entry XSTS*
8	70, 80	8.5 thru 13.0
	100, 110	6.0 thru 13.0
9	90	6.5 thru 10.0
	125	5.0 thru 10.0
	150,175,200,225	4.5 thru 10.0

J600

NSTD	current rating (in amperes)	possible values of the entry XSTS*
10	125-400	3.0 thru 10.0
11	450-600	3.0 thru 10.0

K1200

NSTD	current rating (in amperes)	possible values of the entry XSTS*
12	300,350,400 450,500,600	3.0 thru 10.0
13	700	3.0 thru 10.0
	800	3.0 thru 9.0
14	1000	3.0 thru 7.5
	1200	3.0 thru 6.0

* The maximum value corresponds to the magnetic setting HI and the minimum value corresponds to the magnetic setting LO.

Comments

Breakers E100 line:

Both minimum tripping time-current and maximum tripping time-current characteristic curves are stored with 9 and 11 points respectively under

the symbolic name (YL, XL) for the minimum tripping time-current curve and (YU, XU) for the maximum tripping time-current curve.

Breakers F225, J600, and K100 line:

Long time delay curves and instantaneous curves have been stored separately, under the symbolic names [(XAL, YAL), (XAU, YAU)] and (XIU, YIU) respectively.

Other Subroutines Used

FUNCTN

SUBROUTINE BRKROD

SUBROUTINE BRKROD

General Description

BRKROD is a FORTRAN subroutine which returns the maximum tripping time and the minimum tripping time of any breaker type OD by I-T-E, given the current as a multiple of the pickup current.

Calling Sequence

CALL BRKROD (NSTD, NLTDB, NSTDB, XLTCR, XSTS, XBR, YUPPER, YLOWER)

where

NSTD is the code for the particular breaker we are interested in. NSTD assumes integer values 1, 2, or 3 as follows:

NSTD	1	2	3
BREAKER	OD-3 & OD-300	OD-4 & OD-400	OD-5 & OD-500 OD-6 & OD-600

NLTDB is the long delay setting which assumes integer values 1, 2, or 3 as follows:

NLTDB	1	2	3
Long-time Delay Band	Minimum	Intermediate	Maximum

In case the manufacturer does not specify the long-time delay band (types OD-3 and OD-300), set NLTDB = 1.

NSTDB is the code for the short time band and assumes integer values 0, 1, 2, or 3 as follows:

NSTDB	0	1	2	3
Short-time band	Instantaneous	Minimum	Intermediate	Maximum

XLTCR is the long time coil rating in per unit basis. Suggested values of this entry = .8, 1.0, 1.2, 1.4, or 1.6. Note that the factory setting is XLTCR = 1.0.

XSTS is the instantaneous pickup setting or the short delay pickup setting as a multiple of the trip unit rating. This entry assumes a real value.

XBR is the current in multiples of the trip unit rating. It is a real number.

YUPPER is the variable which will assume the maximum tripping time in the transformed system of coordinates. Therefore, the maximum tripping time in seconds will be:

Maximum tripping time (sec) = .01*(10.0**(5.0*YUPPER))

YLOWER is the variable which will assume the minimum tripping time in the transformed system of coordinates. Therefore, the minimum tripping time in seconds will be:

Minimum tripping time (sec) = .01*(10.0**(5.0*YLOWER))

Comments

Data stored in the subroutine are as follows:

Maximum tripping time

XLU(I), YLU(I)

Minimum tripping time

XLL(I), YLL(I)

I = 1,8 OD-3 and OD-300, long time band

I = 9,16
I = 17,24 Same as above. Their existence eliminates a number of statements.

I = 25,32 OD-4 and OD-400, minimum long time delay band

I = 33,40 OD-4 and OD-400, intermediate long time delay band

I = 41,48 OD-4 and OD-400, maximum long time delay band

I = 49,56 OD-5 and OD-500, OD-6 and OD-600: Minimum long time delay band

I = 57,65 OD-5 and OD-500, OD-6 and OD-600: Intermediate long time delay band

I = 65,72 OD-5 and OD-500, OD-6 and OD-600: Maximum long time delay band

Maximum clearing time

XIU(I), YIU(I)

I = 1,4 Instantaneous direct acting trip device (curve for XSTS=5.0). All types.

Maximum tripping time

XSU(I), YSU(I)

Minimum tripping time

XSL(I), YSL(I)

Short time delay pickup setting: XSTS = 4.0

I = 1,6 OD-4 and OD-400, OD-5 and OD-500: Minimum short time band

I = 7,12 OD-4 and OD-400, OD-5 and OD-500: Intermediate short time band

I = 13,18 OD-4 and OD-400, OD-5 and OD-500: Maximum short time band

Other Subroutines Used

FUNCTN

APPENDIX 2

COORDINATION INDEX COMPUTATION SUBROUTINES

In this section the subroutines RELFUS, RELBRK, FUSBRK and BRKBRK are included. They calculate the coordination indices A2, A1 and RSC, as has been described in part 2, for the pairs of devices, relay-fuse, relay-breaker, fuse-breaker and breaker-breaker respectively, given the type and settings of each device.

Their numerical valuation of the coordination quality between two devices is very useful for the optimization algorithm.

Detailed description of these subroutines follows:

SUBROUTINE FUSBRK

SUBROUTINE FUSBRK

General Description

FUSBRK is a FORTRAN subroutine which calculates the coordiation indices A1, A2, and RSC between a fuse and a breaker when the fuse and the settings of the breaker are specified.

Calling Sequence

CALL FUSBRK(SHORT,RATIO,ITYPFS,NFUSE,ITYPBR,NSTD,NLTDB,NSTDB,XLTCR, XSTS,PICKUP) where

SHORT is the short circuit capacity at the point of application of the breaker or the interrupting capacity of the breaker whichever is smaller.

RATIO is the ratio of the current through the breaker and the current through the fuse under normal operating conditions.

The following entries of the subroutine refer to the fuse

ITYPFS is the code for the type of the fuse. It assumes integer values as follows:

ITYPFS	1	2	3	4
type of fuse	EJ	CLE	CL	SM
name of the corresponding subroutine	FUSEEJ	FUSCLE	FUSECL	FUSESM

NFUSE is the code for the size of the fuse. The selection of this entry is explained in the appropriate subroutine.

The following entries of the subroutine refer to the breaker.

ITYPBR is the code for the type of the breaker. It assumes integer values as follows:

ITYPBR	1	2	3	4	5
type of breaker	AK	LA	DB	Molded case by G.E.	OD
symbolic name of the corresponding subroutine	BRKRAK	BRKRLA	BRKRDB	MCCBGE	BRKROD

NSTD is the code for the tripping device of the breaker (see appropriate subroutine).

NLTDB is the code for the long time delay band(see appropriate subroutine).

NSTDB is the code for the short time delay band (see appropriate subroutine).

XLTCR is a real number referring to the long time coil rating or the ambient temperature and should be selected as explained in the appropriate subroutine.

XSTS is the short time pickup setting (see appropriate subroutine).

PICKUP is the rated pickup value of the tripping device expressed in amperes.

The subroutine will return in a common block the following numbers:

A1: a statistical measure of the relative position of the following two curves: (1) minimum clearing time of the fuse and (2) maximum tripping time of the breaker.

A2: expected reliability of coordination over the possible values of fault currenc.

RSC: reliability of coordination at the short circuit capacity of the system or at the interrupting capacity of the breaker whichever is smaller.

Other Subroutines Used

FUSEEJ
FUSCLE
FUSECL
FUSESM
BRKRAK
BRKRLA
BRKRDB
MCCBGE
BRKROD
FUNCTN

Comments

The computation of the coordination indices is performed under the following assumptions.

(1) The field of the possible fault currents is defined as all the currents between the pickup current times 1.2 of the breaker and the short circuit capacity of the system at the position of the breaker or the interrupting capacity of the breaker whichever is smaller.

(2) The field of the possible fault currents is divided into NN equal segments (transformed current axis, i.e. log scale) and the expectation integral is calculated by summing up the normalized reliability of coordination on each segment.
Suggested value of NN is 20.

(3) The time to operate of both devices is considered equally likely distributed between the maximum and the minimum clearing time (on the transformed time axis).

SUBROUTINE BRKBRK

SUBROUTINE BRKBRK

General Description

BRKBRK is a FORTRAN subroutine which calculates the coordination indices A1, A2, RSC between two breakers when the settings of the breakers are specified.

Calling Sequence

```
CALL BRKBRK(SHORT,RATIO,ITPBR1,NLTDB1,NSTDB1,XLTCR1,XSTS1,PCKUP1,
     ITPBR2,NSTD2,NLTDB2,NSTDB2,XLTCR2,XSTS2,PCKUP2)
```

Note: We call breaker #2 the breaker which should trip first and breaker #1 the other breaker. Symbolic names referring to breaker #2 end with "2" and symbolic names referring to breaker #1 end with "1".

SHORT is the short circuit capacity at the point of application of the breaker #2, or the interrupting capacity of either breaker whichever is smaller.

RATIO is the ratio of the current through the breaker #2 and the current through the breaker #1 under normal operating conditions.

The following entries of the subroutine refer to breaker #1.

ITPBR1 is the code for the type of the breaker #1. It assumes integer values as follows:

ITPBR1	1	2	3	4	5
type of breaker	AK	LA	DB	Molded case by G.E.	OD
symbolic name of the corresponding subroutine	BRKRAK	BRKRLA	BRKRDB	MCCBGE	BRKROD

NSTD1 is the code for the tripping device of the breaker #1 (see appropriate subroutine).

NLTDB1 is the code for the long time delay band of breaker #1 (see appropriate subroutine.

NSTDB1 is the code for the short time delay band of breaker #1 (see appropriate subroutine).

XLTCR1 is a real number referring to the long time coil rating of breaker #1 or the ambient temperature and should be selected as explained in the appropriate subroutine.

XSTS1 is the short time pickup setting of breaker #1 (see appropriate subroutine).

PCKUP1 is the rated pickup value of the tripping device, breaker #1, expressed in amperes.

The following entries of the subroutine refer to breaker #2.
Explanation same as for breaker #1.

ITPBR2
NSTD2
NLTDB2
NSTDB2
XLTCR2
XSTS2
PCKUP2

The subroutine will return in a common block the following numbers:

A1: a statistical measure of the relative position of the following two curves: (1) minimum tripping time of breaker #1, and (2) maximum tripping time of breaker #2.

A2: expected reliability of coordination over the possible values of fault current.

RSC: reliability of coordination at the short circuit capacity of the system or at the interrupting capacity of either breaker whichever is smaller.

Other Subroutines Used

BRKRAK
BRKRLA
BRKRDB
MCCBGE
BRKROD
FUNCTN

Comments

The computation of the coordination indices is performed under the following assumptions:

(1) The field of the possible fault currents is defined as all the currents between the maximum pickup current times 1.2 of the two devices (i.e. the maximum of the two numbers (1.2)x(rated pickup of breaker 1)x(long time coil rating in per unit of breaker 1) and (1.2)x(rated pickup of breaker 2)x(long time coil rating in per unit of breaker 2)) and the short circuit capacity of the system.

(2) The field of the possible fault currents is divided into NN equal segments (transformed current axis, i.e. log scale) and the expectation integral is calculated by summing up the normalized reliability of coordination on each segment.

Suggested value of NN is 20.

(3) The time to trip of both devices is considered equally likely distributed between the maximum and the minimum tripping time. (on the transformed time axis).

SUBROUTINE RELFUS

SUBROUTINE RELFUS

General Description

RELFUS is a FORTRAN subroutine which calculates the coordination indices A1, A2 and RSC between a relay and a fuse when the fuse and the relay setting are specified.

Calling Sequence

CALL RELFUS (SHORT,RATIO,ITYPRL,NTCHR,TDS,PCKPRL,ITYPFS,NFUSE)

where

SHORT is the short circuit capacity at the point of application of the fuse.

RATIO is the ratio of the current through the fuse and the current through the relay under normal operating conditions.

The following entries of the subroutine refer to the relay ITYPRL is the code for the type of the relay. It assumes integer values as follows:

ITYPRL	1	2
type of relay	IAC	CO
name of the corresponding subroutine	RELIAC	RELACO

NTCHR is the code of the family of the relay characteristics (see appropriate subroutine).

PCKPRL is the pickup current of the relay.

The following entries of the subroutine refer to the fuse

ITYPFS is the code for the type of the fuse. It assumes integer values as follows:

ITYPFS	1	2	3	4
type of fuse	EJ	CLE	CL	SM
name of the corresponding subroutine	FUSEEJ	FUSCLE	FUSECL	FUSESM

NFUSE is the code for the size of the fuse. The selection of this entry is explained in the appropriate subroutine.

The subroutine will return in a common block the following numbers:

A1: a statistical measure of the relative position of the following two curves: (1) mean operating time of the relay and (2) maximum clearing time of the fuse.

A2: expected reliability of coordination over the possible values of fault current.

RSC: reliability of coordination at the short circuit capacity of the system..

Other Subroutines Used

RELIAC
RELACO
FUSEEJ
FUSCLE
FUSECL
FUSESM
FUNCTN

Comments

The computation of the coordination indices is performed under the following assumptions:

(1) The field of the possible fault currents is defined as all the currents between the pickup current times 1.2 of the relay and the short circuit capacity of the system at the position of the fuse.

(2) The field of the possible fault currents is divided into NN equal segments (transformed current axis, i.e. log scale) and the expectation integral is calculated by summing up the normalized reliability of coordination on each segment.

Suggested value of NN is 20.

(3) The relay time to trip is considered equally likely distributed on the interval $t'_N \pm .03$ where t'_N is the nominal value on the transformed time axis. The fuse time to melt is considered equally likely distributed between the minimum melting time and the maximum clearing time.

SUBROUTINE RELBRK

SUBROUTINE RELBRK

General Description

RELBRK is a FORTRAN subroutine which calculates the coordination indices A1, A2 and RSC between a relay and a breaker when the relay and breaker settings are specified.

Calling Sequence

CALL RELBRK (SHORT,RATIO,ITYPRL,NTCHR,TDS,PCKPRL,ITYPBR,NSTD,NLTDB,
NSTDB,XLTCR,XSTS,PCKPBR)

where

SHORT is the short circuit capacity at the point of application of the breaker or the interrupting capacity of the breaker whichever is smaller.

RATIO is the ratio of the current through the breaker and the current through the relay. Under normal operating conditions.

The following entries of the subroutine refer to the relay.

ITYPRL is the code for the type of the relay. It assumes integer values as follows:

ITYPRL	1	2
type of relay	IAC	CO
name of the corresponding subroutine	RELIAC	RELACO

NTCHR is the code of the family of the relay characteristics (see appropriate subroutine).

PCKPRL is the pickup current of the relay.

The following entries of the subroutine refer to the breaker.

ITYPBR is the code for the type of the breaker. It assumes integer values as follows:

ITYPBR	1	2	3	4	5
type of breaker	AK	LA	DB	Molded case by G.E.	OD
symbolic name of the corresponding subroutine	BRKRAK	BRKRLA	BRKRDB	MCCBGE	BRKROD

NSTD is the code for the tripping device of the breaker (see appropriate subroutine).

NLTDB is the code for the long time delay band (see appropriate subroutine).

NSTDB is the code for the short time delay band (see appropriate subroutine).

XLTCR is a real number referring to the long time coil rating or the ambient temperature and should be selected as explained in the appropriate subroutine.

XSTS is the short time pickup setting (see appropriate subroutine).

PCKPBR is the rated pickup current of the breaker.

The subroutine will return in a common block the following numbers:

A1: a statistical measure of the relative position of the following two curves: (1) mean operating time of the relay and (2) maximum tripping time of the breaker.

A2: expected reliability of coordination over the possible values of fault current.

RSC: reliability of coordination at the short circuit capacity of the system.

Other Subroutines Used

RELIAC
RELACO
BRKRAK
BRKRLA
BRKRDB
MCCBGE
BRKROD
FUNCTN

Comments

The computation of the coordination indices is performed under the following assumptions:

(1) The field of the possible fault currents is defined as all the currents between the maximum pickup current times 1.2 of the two devices (i.e. the maximum of the two numbers (1.2)x (relay pickup current)x(ratio) and (1.2)x(rated pickup of the breaker)x(long time coil rating in per unit of the breaker)) and the short circuit capacity of the system.

(2) The field of the possible fault currents is divided into NN equal segments (transformed current axis, i.e. log scale) and the expectation integral is calculated by summing up the normalized reliability of coordination on each segment. Suggested value of NN is 20.

(3) The relay time to trip is considered equally likely distributed on the interval $t'_N \pm .03$ where t'_N is the nominal value on the transformed time axis. The breaker time to trip is considered equally likely distributed between the maximum and the minimum tripping time (on the transformed time axis).

APPENDIX 3

OVERHEATING AND MOTOR STARTING CURRENTS PROTECTION SUBROUTINES

Two subroutines are presented here. The first one, CHECKH, assesses protection of the system against overheating. It actually checks if the current limiting fuse employed in the system can clear before a fault current can cause any heat damage to the system. The second one, CHECKS, assesses protection of the system against unnecessary tripping of the breakers due to motor starting inrush currents. It actually checks if the breaker closest to the motor will not trip under normal motor starting conditions.

Detailed description follows:

SUBROUTINE CHECKH

SUBROUTINE CHECKH

General Description

CHECKH is a FORTRAN subroutine which checks if the fuse clears in less time than that which might damage the system.

Calling Sequence

CALL CHECKH (SHORT,ITYPFS,NFUSE,NCODE,NPASS)

where

SHORT is the short circuit capacity of the system at the point of application of the fuse.

ITYPFS is the code for the type of the fuse. It assumes integer values as follows:

ITYPFS	1	2	3	4
type of fuse	EJ	CLE	CL	SM
name of the corresponding subroutine	FUSEEJ	FUSCLE	FUSECL	FUSESM

NFUSE is the code for the size of the fuse (see appropriate subroutine).

NCODE offers an option:

if NCODE = 0, no check will be made and the fuse will "pass."

Any other value of NCODE will yield in checking if the fuse meets the protection requirements.

NPASS is the code which will be returned by the subroutine.

If NPASS equals 2, the fuse does not meet the protection requirements.

If NPASS equals 1, the fuse passes the protection requirements.

Comments

The designer should provide the following information: The heat curve defined with no more than 20 points, under the symbolic name (XA,YA).

XA: current in amperes

YA: time in seconds

Other Subroutines Used

FUNCTN
FUSEEJ
FUSCLE
FUSECL
FUSESM

Note: In almost all cases of the KSC power system the prohibitive heat dissipation in case of a fault will occur in the nearest transformer. Therefore the designer should determine the heat curve of the transformer in most of the cases.

SUBROUTINE CHECKS

SUBROUTINE CHECKS

General Description

CHECKS is a FORTRAN subroutine which checks if the minimum tripping curve of a feeder breaker is above the starting current curve (time vs current) of a motor.

Calling Sequence

```
CALL CHECKS (SHORT,ITYPBR,NSTD,NLTDB,NSTDB,XLTCR,XSTS,PICKUP,NCODE,
     NPASS)
```

where

SHORT is the short circuit capacity of the system or the interrupting capacity of the breaker whichever is smaller.

The following entries of the subroutine refer to the breaker.

ITYPBR is the code for the type of the breaker. It assumes integer values as follows:

ITYPBR	1	2	3	4	5
type of breaker	AK	LA	DB	Molded case by G.E.	OD
symbolic name of the corresponding subroutine	BRKRAK	BRKRLA	BRKRDB	MCCBGE	BRKROD

NSTD is the code for the tripping device of the breaker (see appropriate subroutine).

NLTDB is the code for the long time delay band (see appropriate subroutine.

NSTDB is the code for the short time delay band (see appropriate subroutine).

XLTCR is a real number referring to the long time coil rating or the ambient temperature and should be selected as explained in the appropriate subroutine.

XSTS is the short time pickup setting (see appropriate subroutine).

PICKUP is the rated pickup value of the tripping device expressed in amperes.

NCODE offers an option:

If NCODE = 0, no check will be made and the breaker will "pass."
Any other value of this entry will yield a normal run of the subroutine.

NPASS is code which will be returned by the subroutine

If NPASS = 1 (2), the minimum tripping curve of the breaker lies (does not lay) above the starting current curve of the motor.

Comments

The designer should provide the starting current curve of the motor under the symbolic name (XB,YB) and with no more than 20 points.

Note: XB: current in amperes
YB: time in seconds

Other Subroutines Used

BRKRAK
BRKRLA
BRKRDB
MCCBGE
BRKROD
FUNCTN

APPENDIX 4

PLOTTING SUBROUTINES

Two subroutines are included here. The first one can overlay the characteristics of at most seven devices, namely, two relays, two fuses and three breakers. It has been designed to be used independently. It provides an excellent illustration of the coordination status.

The second subroutine is similar to the one above. It can overlay the characteristics of at most four devices, namely, one fuse and three breakers. Its format is readily applicable to the most common case of substation at the Kennedy Space Center power system. It can be called by the optimization subroutine to plot the optimal curves of the employed devices (see Appendix 5).

Detailed discription follows:

A. Plotting Routine

This routine can plot the characteristics of 7 protective devices, namely, two relays, two fuses and three breakers.

It requires 8 data cards.

The format of the data cards follows:

1st data card

1-10	current transformation ratio between relay A & B
11-20	current transformation ratio between relay B & fuse A
21-30	current transformation ratio between fuse A & fuse B
31-40	current transformation ratio between fuse B & breaker A
41-50	current transformation ratio between breaker A & breaker B
51-60	current transformation ratio between breaker B & breaker C
61	code for the location of the substation = 1 if in Launch Complex 39 = 2 if in Industrial Area

2nd data card

Refers to relay A. If relay A does not exist leave the card blank. If relay A exists fill in as follows:

1-5	symbolic name of the bus where the relay is applied
6-15	the relay's pickup current setting

16-25	the interrupting capacity of the associated breaker
26-30	the code for the relay type 1 for Relay IAC 2 for Relay CO
31-35	the code for the particular characteristic of the relay (see appropriate subroutine)
36-40	time dial setting of the relay

3rd data card

Refers to relay B. Explanation and format are same as for relay A.

4th data card

Refers to fuse A. If fuse A does not exist leave the card blank. If fuse A does exist fill in as follows:

1-5	symbolic name of the bus where the fuse is applied		
6-10	code for the type of the fuse		
	= 1	type	EJ
	2	type	CLE
	3	type	CL
	4	type	SM
11-15	code for the size of the fuse		
16-25	current rating of the fuse		

5th data card

Refers to fuse B. Format is the same as per fuse A.

6th data card

Refers to breaker A. If breaker A does not exist leave the card blank. If breaker A does exist fill in as follows:

1-5	symbolic name of the bus where the breaker is applied		
6-15	rated pickup setting in amperes		
16-25	interrupting capacity of the breaker in amperes		
29-30	code for the type of the breaker		
	= 1	type	AK
	2	type	LA
	3	type	DB
	4	type	Molded case by G.E.
	5	type	OD
31-35	code for the series trip device		
36-40	code for the long time delay band		
41-45	code for the short time delay band		
46-55	long time coil rating in per unit		
56-65	short time pickup current setting		

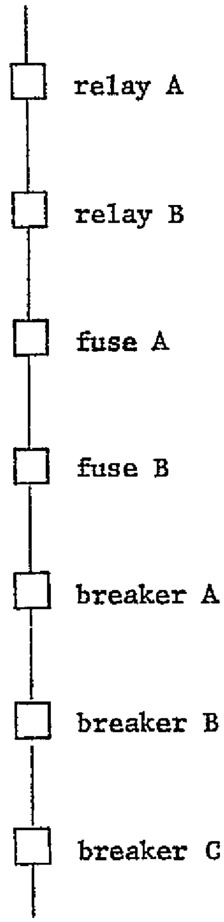
7th data card

Refers to breaker B. Format as per breaker A.

8th data card

Refers to breaker C. Format as per breaker A.

The following scheme illustrates the general case covered by the plotting routine.



Of course, in a specific case some of the referred devices might be missing. Insert blank data cards for those devices and the program will neglect them.

Calling Procedure

To call the plotting routine it is sufficient to provide the eight data cards. The device characteristic subroutines should be included in the program

Comments

For each device, the set of currents applicable to the case is defined as all the currents between the pickup value (or rated current for fuses) and the short circuit capacity of the system at the position of application of the device. This interval is then divided in forty equal subintervals (always on the transformed axis, i.e. $x = C_1 \log I + C_1'$). For the middle value of each subinterval the operating time is calculated by calling the appropriate device subroutine. Therefore, the curve (or the curves - minimum and maximum operating times) of each device is determined with forty points each.

The datagraphics 4460 system is called to put these points on a common coordinate system and then draw a line through the points belonging to the same curve.

Note that the routine is written in FORTRAN

Other Subroutines Used

RELIAC
RELACO
FUSEEJ
FUSECL
FUSCLE
FUSESM
BRKRAK
BRKRLA
BRKROD
MCCBGE
BRKRDB
FUNCTN

B. Subroutine PLOT

Subroutine PLOT is a FORTRAN subroutine which can overlay the time vs current characteristics of at most four devices, namely, one fuse, and three breakers.

Calling Sequence

```
CALL PLOT (RTFA,RTAB,RTBC,ITPFF,NFUSEO,SHFUSE,PCKPBA,BAINTC,
    ITPBA,NSTDAO,NLTBAO,NSTBAO,XLTCAO,XSTSAO,SHBA,PCKPBB,BBINTC,
    ITPBB,NSTDBO,NLTBBO,NSTBBO,XLTCBO,XSTSBO,SHBB,PCKPBC,BCINTC,
    ITPBC,NSTDCO,NLTBCO,NSTBCO,XLTCCO,XSTSCO,SHBC).
```

where

RTFA current transformation ratio between fuse and breaker A

RTAB current transformation ratio between the breaker A and B

RTBC current transformation ratio between the breakers B and C

ITPFF code for the type of fuse (see subroutine RELFUS)

NFUSEO code for the size of fuse (see appropriate subroutine)

SHFUSE the short circuit capacity of the system at the point of application of the fuse.

Following entries refer to breaker A.

PCKPBA the rated pickup current of breaker A

BAINTC the breaker A interrupting capacity

ITPBA code for the type of breaker A (see subroutine BRKBRK).

NSTDAO code for the series trip device of breaker A

NLTBAO code for the long time delay band of breaker A

NSTBAO code for the short time delay band of breaker A

XLTCAO the long time coil rating of breaker A (in per unit)

XSTSAO the short time pickup value of breaker A in multiples of the rated pickup circuit

SHBA the short circuit capacity of the system at the position of application of breaker A.

Following entries refer to breaker B. Explanation in similar as per breaker A.

PCKPBB
BBINTC
ITPBB
NSTDBO
NLTBBO
NSTBBO
XLTCBO
XSTSBO
SHBB

Following entries refer to breaker C. Explanation is similar as per breaker A

PCKPBC
BCINTC
ITPBC
NSTDCO
NLTBCO
NSTBCO
XLTCCO
XSTSCO
SHBC

Comments

This subroutine is part of the plotting program. Explicity, it retains the part of the program which refers to fuse B, breaker A, breaker B and breaker C.

APPENDIX 5

COORDINATION OPTIMIZATION SUBROUTINES

General

The purpose of these subroutines is to determine optimal settings of existing systems by utilizing the concepts developed in part 2.

The accepted procedure is very simple. For an acceptable combination of devices and setting the coordination indices are calculated. Then a weighted average is computed. This average is the basis of comparison. The configuration with the highest weighted average index is defined as optimal.

The average coordination index is defined by the form

A.C.I. = XA*A2+XB*A1+XC*RSC

with XA+XB+XC = 1.0

XA, XB and XC can be determined by the user according to his philosophy of coordination and according to the nature of the system under study.

For example, if coordination at the short circuit capacity only is desired, it is sufficient to set

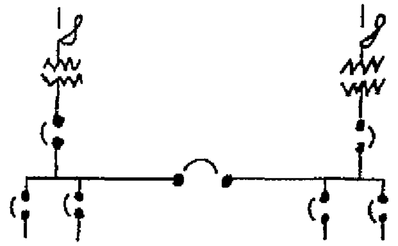
XA = 0.0
XB = 0.0
XC = 1.0

The above extreme case reveals that by assigning appropriate values to these coefficients it is possible to satisfy different tendencies in the coordination philosophy.

Main Program FBBBCØ

General Description

Program FBBØC is written in FORTRAN. It determines the optimum coordinated settings of the involved protective devices by searching and comparing all possible settings. The comparison is executed by means of a predescribed criterion which can be modified by any user, if desirable. In particular the program has been written in connection with the following very common case of substations



Required Data

Before the data cards the user should provide three cards on which he can punch anything he wishes. This text will be the title of the output.

The program requires 7 data cards to be filled in as follows:

1st data card

1-6	symbolic name of the bus where the fuse is located
7-12	symbolic name of the bus where the breaker A is located
13-18	symbolic name of the bus where the breaker B is located
19-24	symbolic name of the bus where the breaker C is located

25	code for option #1 (see options)
26	code for option #2 (see options)
27	code for the area where the substation is located = 1 if in Launch Complex 39 = 2 if in Industrial Area
28	code for option #3 (see options)

<u>2nd data card</u>

1-10	interrupting capacity of breaker A
11-20	interrupting capacity of breaker B
21-30	interrupting capacity of breaker C

<u>3rd data card</u>

1-10	current transformation ratio between fuse and the breaker A
11-20	current transformation ratio between the breakers A and B
21-30	current transformation ratio between the breakers B and C
31-40	the rated pickup current in amperes of breaker A
41-50	the rated pickup current in amperes of breaker B
51-60	the rated pickup current in amperes of breaker C

4th data card

1-5	code for the smaller size candidate fuse
6-10	code for the larger size candidate fuse
11-15	step (insert 1 to include all the intermediate sizes)
16-20	code for the type of fuse 1 for fuses type EJ 2 for fuses type CLE 3 for fuses type CL 4 for fuses type SM

note: to determine correspondence between fuse size and code consult the subroutine which refers to the particular type of the fuse.

5th, 6th, and 7th data cards

The above cards nominate all the candidate breaker settings to be considered by the program. The format is identical for the three cards as follows:

1-5	smaller	code for the series trip device
6-10	larger	
11-15	step	
16-20	smaller	code for the long time delay band
21-25	larger	
26-30	step	
31-35	smaller	code for the short time delay band
36-40	larger	
41-45	step	

46-50	smaller	the long time coil rating expressed in percent (integer)
51-55	larger	
56-60	step	
61-65	smaller	the short time pickup setting (integer)
66-70	larger	
71-75	step	
76-80		code for the type of the breaker as follows:

1 for breakers type AK
2 for breakers type LA
3 for breakers type DB
4 for molded case breakers by G.E.
5 for breaker type OD

note: the user should study the selection of data for the worked example (attached) in order to resolve ambiguities.

Subroutines Used

FUSBRK
BRKBRK
CHECKH
CHECKS
FUSEEJ
FUSCLE
FUSECL
FUSESM
BRKRAK
BRKRLA
BRKRDB
MCCBGE
BRKROD
FUNCTN

Options

option #1 The user can secure protection of the system against overheating by inserting any number except zero (0) in column 25 of the first data card and providing the necessary data in subroutine CHECKH (see subroutine for further information)

option #2 If the system includes motors of size commensurate to the rating of the system, the program provides the option to secure the system against unnecessary tripping due to the motor starting currents. In order to do so fill in column 26 of the first data card any number except zero (0) and provide the necessary data in subroutine CHECKS (see subroutine for further information).

option #3 This option refers to the type of the substation:

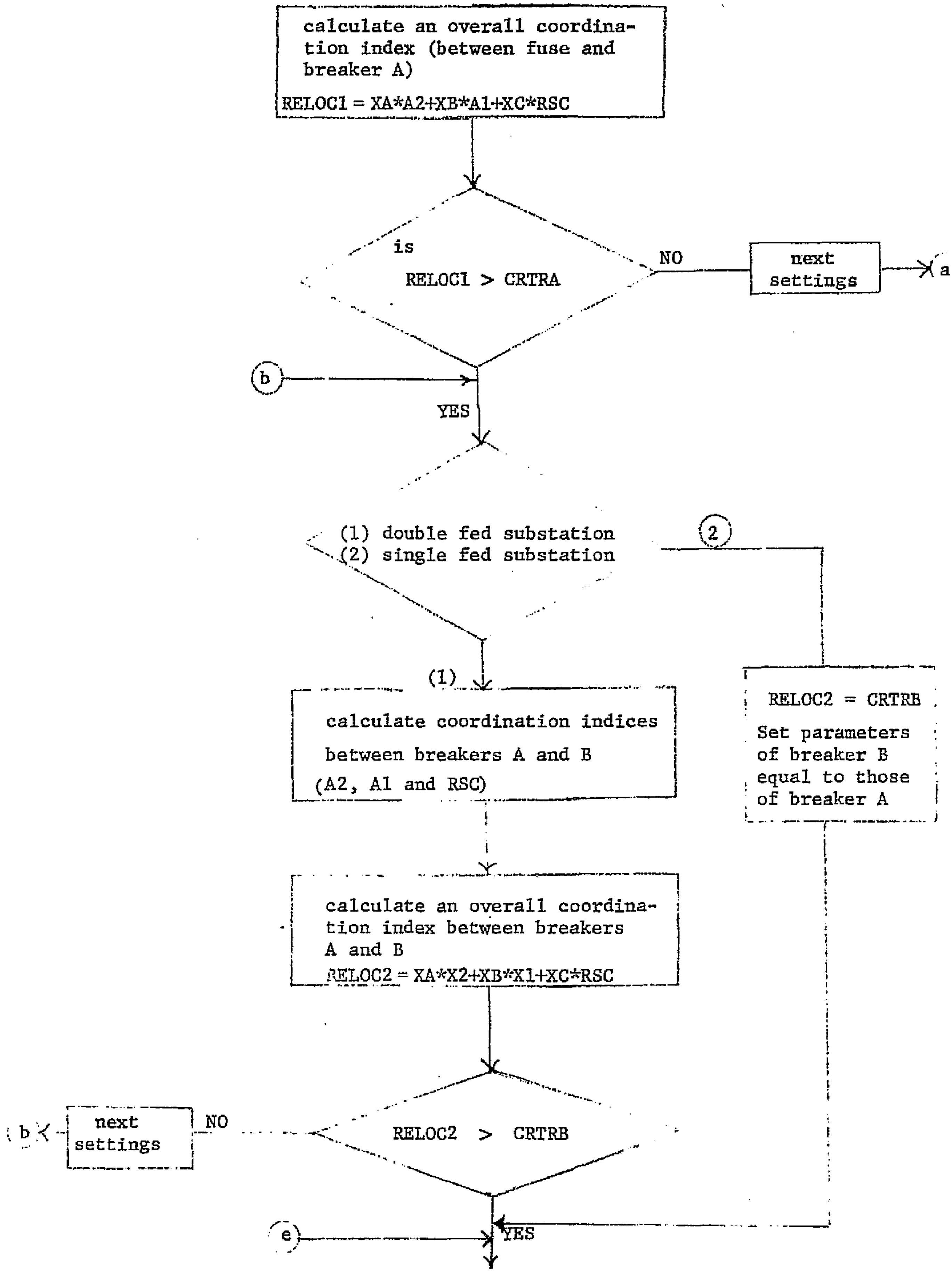
(1) Double fed substation with primary fuse, main secondary breaker, tie line breaker and feeder breakers is recognized with the code 0 punched in column 28 of the first data card.

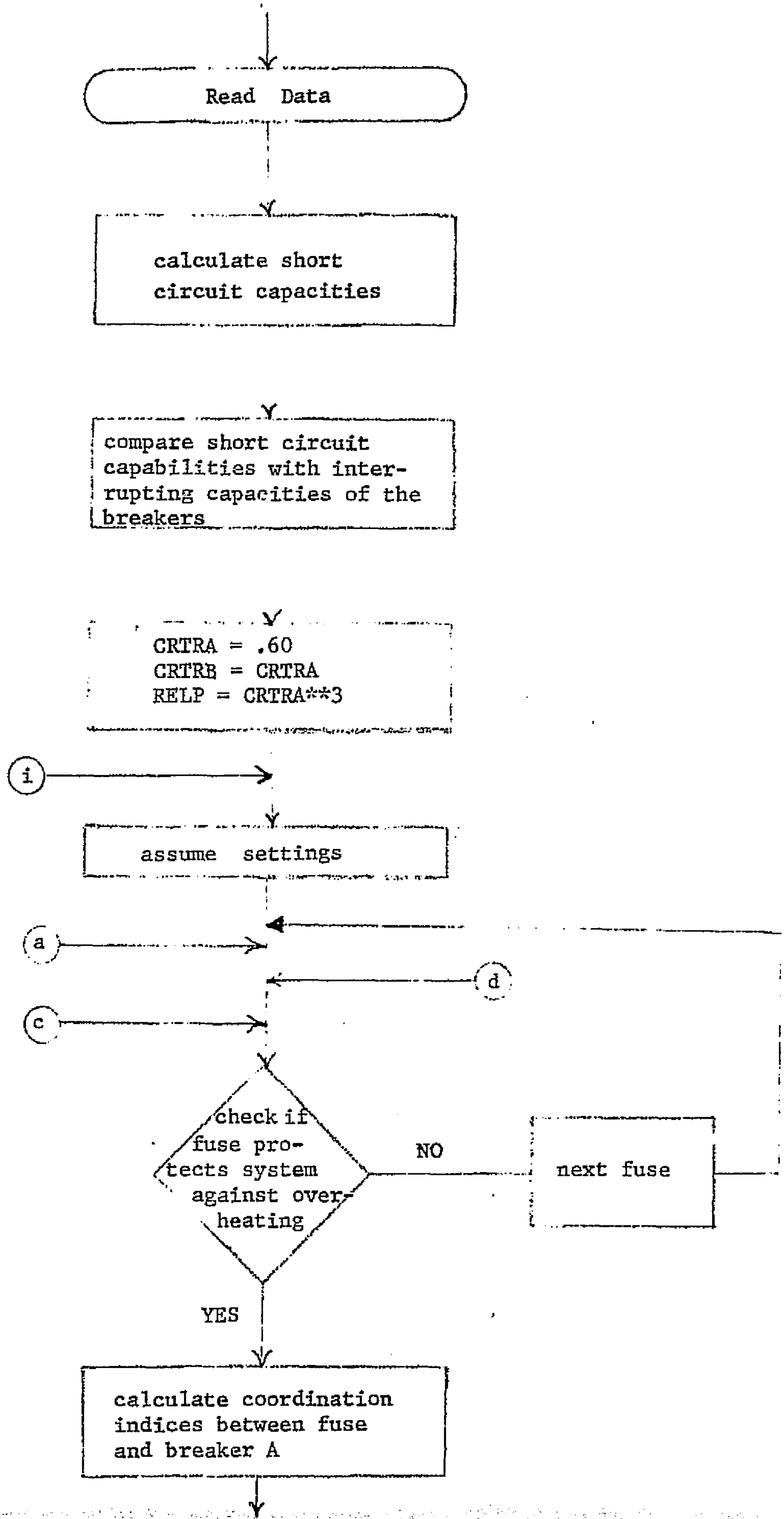
(2) Single fed substation with primary fuse, main secondary breaker and feeder breakers is recognized with the code 1 punched in column 28 of the first data card.

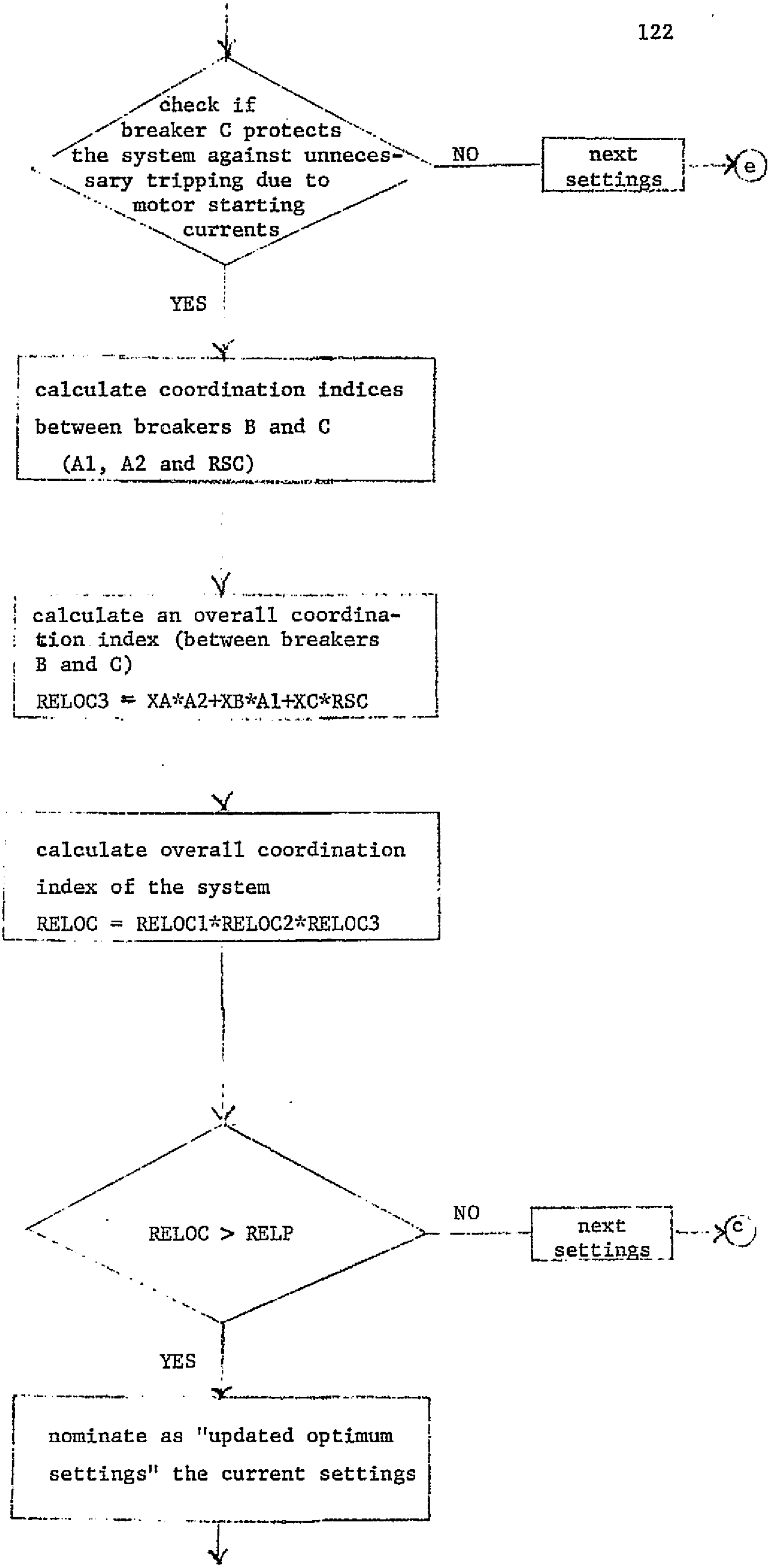
In the last case, where the tie line breaker is missing, the sixth data card which refers to the missing tie line breaker should be a duplicate of the fifth data card.

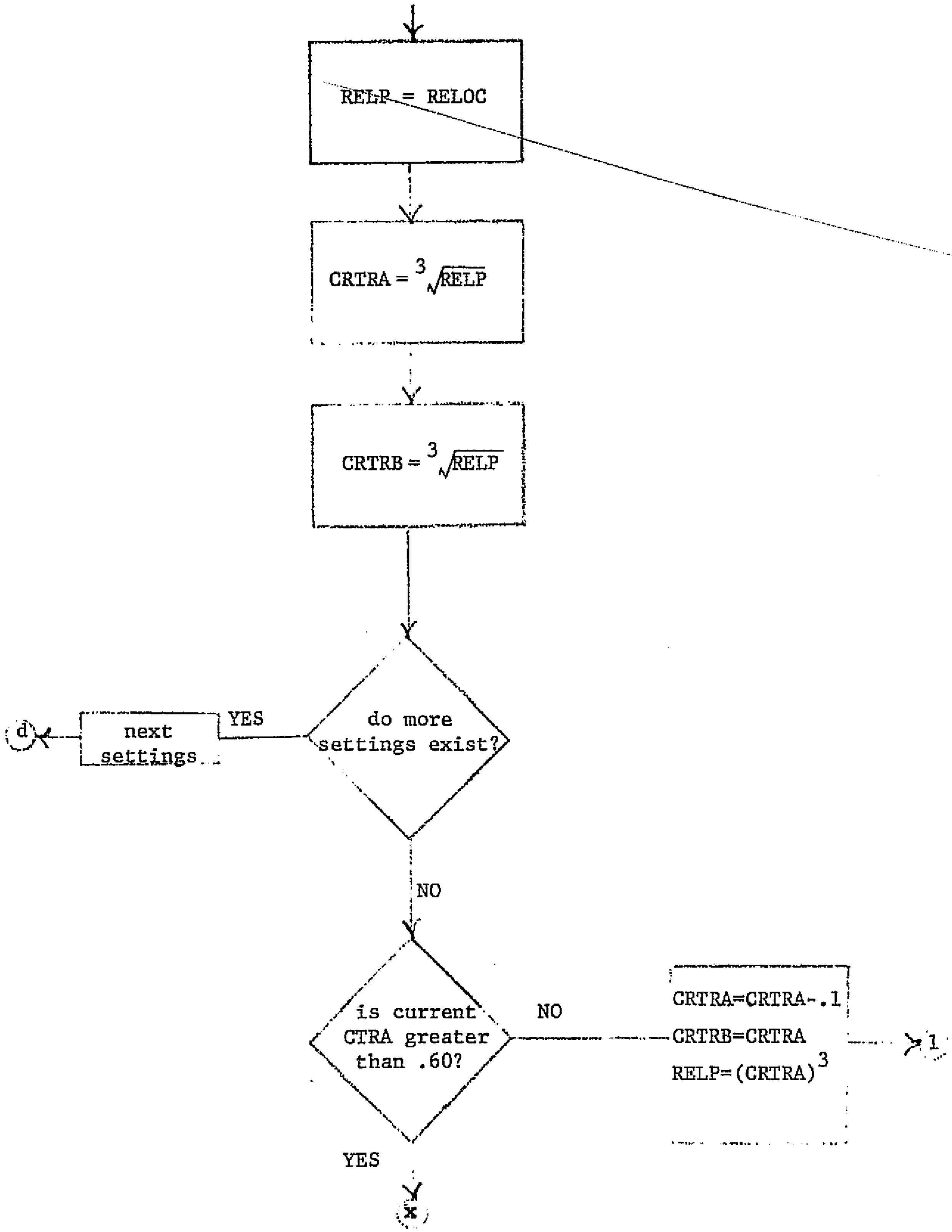
Flow Chart

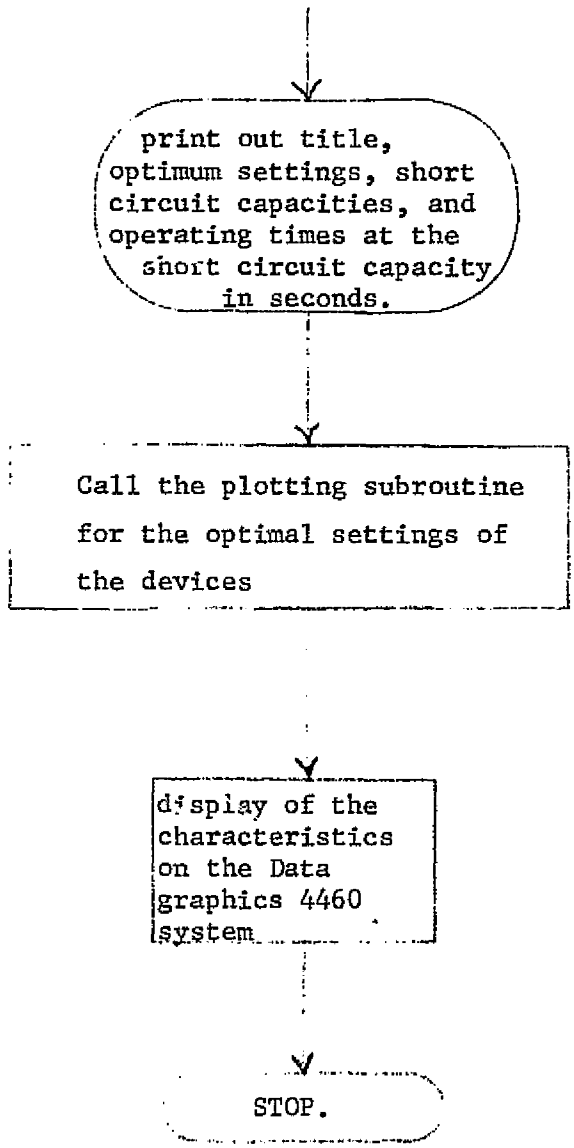
A flow chart of the program is presented in the next pages.


calculate an overall coordination index (between fuse and breaker A)
RELOC1 = XA*A2+XB*A1+XC*RSC
is
RELOC1 > CRTRA
NO
next settings
a
b
YES
(1) double fed substation
(2) single fed substation
2
(1)
calculate coordination indices between breakers A and B (A2, A1 and RSC)
RELOC2 = CRTRB
Set parameters of breaker B equal to those of breaker A
calculate an overall coordination index between breakers A and B
RELOC2 = XA*X2+XB*X1+XC*RSC
b
next settings
NO
RELOC2 > CRTRB
e
YES


Read Data
calculate short circuit capacities
compare short circuit capabilities with interrupting capacities of the breakers
CRTRA = .60
CRTRB = CRTRA
RELP = CRTRA**3
i
assume settings
a
d
c
check if fuse protects system against overheating
NO
next fuse
YES
calculate coordination indices between fuse and breaker A


check if breaker C protects the system against unnecessary tripping due to motor starting currents
NO
next settings
e
YES
calculate coordination indices between breakers B and C (A1, A2 and RSC)
calculate an overall coordination index (between breakers B and C)
RELOC3 = XA*A2+XB*A1+XC*RSC
calculate overall coordination index of the system
RELOC = RELOC1*RELOC2*RELOC3
RELOC > RELP
NO
next settings
c
YES
nominate as "updated optimum settings" the current settings


RELP = RELOC
CRTRA = $\sqrt[3]{RELP}$
CRTRB = $\sqrt[3]{RELP}$
do more settings exist?
YES
next settings
d
NO
is current CTRA greater than .60?
NO
CRTRA=CRTRA-.1
CRTRB=CRTRA
RELP=(CRTRA)^3
1
YES
x


print out title, optimum settings, short circuit capacities, and operating times at the short circuit capacity in seconds.
Call the plotting subroutine for the optimal settings of the devices
display of the characteristics on the Data graphics 4460 system
STOP.

The flow chart shows the mechanics of the program and makes obvious that it can be modified to meet other requirements. For example, suppose that a relay controlled breaker is in place of the breaker A. In this case it would be sufficient to make only two changes:

(1) Instead of calculating the coordination indices between the fuse and the breaker A (subroutine FUSBRK), the coordination indices between the fuse and the relay should be computed by calling the subroutine RELFUS.

(2) Instead of calculating the coordination indices between the breakers A and B (subroutine BRKBRK), the coordination indices between the relay and the breaker B should be computed by calling the subroutine RELBRK.

With this we encourage users to modify and/or supplement the routines according to their needs.